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TRUCK CROP PLANTS

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TRUCK CROP PLANTS

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AND

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FIRST EDITION

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PREFACE

The study of Truck Crops in courses of university grade is a comparatively recent development. There has been considerable research in this field, to serve as a foundation for well-organized courses of a fundamental type. But such material has been widely scattered in experiment-station publications and in scientific journals of the United States and other countries. Thus, much valuable work has never received the attention it merits and is almost unavailable to the average student, to growers, and to the professional man in the field, working at a distance from educational institutions and library facilities. In any science, moreover, where new knowledge is accumulating rapidly, it is well to pause occasionally and make a survey of what has been accomplished. Most teachers and investigators are so engrossed in accumulating new facts dealing with their own lines of interest, that the collation of existing knowledge, with a broad survey of the whole field, is likely to be neglected. Such a survey reveals many obvious gaps and deficiencies, which need to be filled in by new investigations.

This text and reference book is the outgrowth of material used by the authors in their courses in Truck Crops in agricultural colleges. The material is designed mainly for those who have had an elementary course in Truck Crops as well as some work in botany and chemistry. Little space is devoted to cultural details with which the practical grower is already familiar and which the student always must learn from experience, in the light of local conditions.

The aim has been to make the plant the basis for discussion rather than certain practices or certain phenomena. The student's interest is more easily aroused when the object of consideration is somewhat familiar and of some economic importance. In the teaching of botany or genetics, plants are used to demonstrate certain laws or fundamental principles. But in courses in the applied field, we believe that the crop or the plant should be used as the unit of consideration and the sciences used to explain cultural practices and plant behavior. We do not believe that it is possible to say that any of the sciences do not belong to this field. If a science helps to elucidate certain phenomena or explains the reason for certain practices, we have sufficient reason for using it. We take the stand that all the sciences exist for the benefit or pleasure of mankind and should be used to meet this end, and we have here an opportunity to show the student how various sciences may be put to practical application.

It is intended that this book shall stimulate rather than dispense with class discussion. The instructor will desire to amplify upon certain crops where they are especially important and will in all cases have to discuss cultural practices with local adaptations in view. Little material is incorporated regarding manuring or nutrition, mainly because little work has been done on truck-crop plants except in an empirical way. It is hoped that by the time a revised edition is necessary, much additional material on nutrition of the truck-crop plants will be available.

Insects and diseases have been discussed in considerable detail, because their control is so intimately associated with production and even with transportation and marketing. Insect and disease control present problems of great economic importance, and an effort has been made here to harmonize these matters with production practices. No attempt at completeness has been made, however, and there is no intention of replacing the excellent manuals already available in these fields.

It is the hope of the authors that this book will satisfy more than the purely economic side. There should be happiness and enjoyment in the growing and handling of vegetable crops. Moreover, the gardner working with various crops or plants and knowing something about their behavior, structure, manner of growth, and relation to their environment is usually more completely satisfied than one working with the same crops and knowing nothing of the secrets which they hold.

We are keenly aware of the many deficiencies in the text—the great difference between what this text is and what we would like to have it be. The authors will deeply appreciate having called to their attention mistakes in the subject matter and opportunities for improvement.

The following books have been drawn upon frequently for subject matter: "Manual of Cultivated Plants," by L. H. Bailey; "Sturtevant's Notes on Edible Plants" by U. P. Hedrick; and "Botany of Crop Plants," by W. W. Robbins. Mr. C. L. Christensen of the U. S. Department of Agriculture Bureau of Agricultural Economics, kindly furnished data on shipping seasons and carlot movements. We wish to express our appreciation also to the following men for reading various parts of the manuscript and offering suggestions and criticisms: Messrs. Charles O. Appleman, John Bushnell, O. L. Coulter, F. G. Cuthbertson, L. L. Harter, T. C. Johnson, P. B. Kennedy, F. Kotowski, J. W. Leslie, E. W. Lindstrom, W. H. Nixon, O. H. Pearson, R. G. Risser, W. W. Robbins, L. R. Robinson, J. B. Scherrer, M. Shapovalo, William Stuart, L. W. Wheeler, Paul Work, and E. O. Pieper.

The authors alone are responsible for the choice of subject matter and for the balance of the various chapters.

THE AUTHORS.

DAVIS, CALIF.,
October, 1927.

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INTRODUCTION

In its historical background, the business of producing vegetable crops is a branch of horticulture. With increasing specialization, the development of practices suitable for large-scale operations, and the increasing volume of production, however, most of the ancient aspects of "gardening," as we commonly understand that term, have disappeared from commercial vegetable growing. Today the main connection between the vegetable business and other horticultural fields is in the marketing. Very much the same methods of packing, shipping, and selling are employed for vegetables and fruits. And the actual selling of both classes of produce is, in general, carried on by the same people. There is, however, little in common between the growers of vegetables and fruits. In many cases, the methods of production of vegetables are very similar to those used for field crops.

TYPES OF VEGETABLE PRODUCTION

Six more or less specialized types of vegetable production may be recognized: (1) seed growing, (2) vegetable forcing, (3) production of canning and pickling crops, (4) home gardening, (5) market gardening, and (6) truck farming. There is, however, no definite line of cleavage between some of the above types. It is often rather difficult to tell just where one leaves off and the other begins. Several of these different types of vegetable production may be practiced on the same farm. Market gardening and vegetable forcing are often practiced together, especially in the North and East. In California the growing of vegetable seeds and truck crops on the same ranch is common. In many regions growers produce crops for either canning or shipping.

Seed Growing.—Production of vegetable seeds in the United States was of rather slow development at first, because most vegetables are of Old World origin, and we were for many years dependent upon Europe not only for our varieties but largely for the actual production of vegetable seeds. This is still true of a few crops, but in most cases nearly all of the American seed supply is now grown in the United States, and a few kinds are exported extensively to other countries. The seed business has itself become specialized into different lines—specialty growers, breeders, contract growers, wholesalers, and retailers. No other phase of the vegetable business makes greater demands upon botanical and genetical science than seed production. Pure varieties of seed and varieties of

high quality, yielding power, and suitability for market are fundamental to success in all lines of vegetable production. The seed grower has the responsibility of developing and maintaining such varieties. The seed business offers excellent opportunities to trained plant breeders who can use scientific principles to produce practical results. Many of the large seed growers, shippers, and canners are already employing specialists to help place their plant improvement work on a scientific basis.

Vegetable Forcing.—The production of out-of-season vegetables, under glass, expanded very rapidly for a number of years, as we learned how to build better greenhouses and how to operate them more economically. The high purchasing power of the American public and the desire to have fresh vegetables of the best quality the year round have also favored the development of vegetable forcing. The increased shipments during winter and spring from the South, from California, and from Mexico and the West Indies, however, have tended to curtail the market for forced vegetables. Vegetable forcing is largely confined to the Northeast and North Central states. Tomatoes, cucumbers, and lettuce are the crops most usually forced.

Home Gardening.—Although not a phase of commercial vegetable production, home gardening is important because of the vast number of people interested in it and the large volume of food produced. In home gardens, a large number of crops suited to outdoor culture under the prevailing conditions of soil and climate are grown for use on the gardener's own table. Farmers engaged in other lines of agriculture and town dwellers who have available land should grow vegetables for home use not only because of the cash value of the produce but because of the superior quality of certain vegetables when they are consumed fresh from the garden. Sweet corn, peas, and asparagus may be mentioned as examples of vegetables in which freshness is most desirable. The health-giving properties of vegetables are becoming highly appreciated as a result of modern research in dietetics, and for this reason, also, home gardening should be encouraged. Then the home garden should afford as well an element of pleasure. Most people like to see plants grow and take pride in making them grow well. Although there is less of the spirit and enthusiasm of the amateur in the United States than in older countries, these are well worth encouraging. Home gardening is also of importance to the commercial grower, especially the seedsmen, for the home gardeners use the larger part of the vegetable seed grown as well as vast numbers of vegetable plants.

Canning and Pickling Crops.—The leading vegetables canned commercially are tomatoes, sweet corn, peas, asparagus, spinach, beans, and beets. The quantity canned has increased enormously in recent years. According to the United States Census Report for canned goods, there was packed in 1925, 94,580,742 standard cases of vegetables as compared

with 25,375,534 standard cases of fruit. Although the canning industry is widely distributed, the production of vegetables for canning and the canneries themselves are largely centered in regions where the soil and climate are especially suitable for certain crops. Thus, asparagus and spinach for canning are produced mostly in certain districts of California; peas, in Wisconsin and New York; sweet corn, in Iowa, Illinois, and Maryland; and beans in Maryland and New York. On the other hand, tomatoes and some of the minor crops are grown and canned in many regions where the canner's seasonal operations permit of handling them. Cucumbers are the most important crop for pickling, over half of the cucumbers grown being so used. This industry is centralized in Michigan and adjacent states.

Occasionally the suggestion is made that canneries be operated in connection with city markets to absorb the surplus during periods of oversupply. High quality and freshness of the raw products is essential to the production of high-grade canned goods, however, and it is not likely that these requirements would be met in the canning of shop-worn or stale vegetables which had remained for a period unsold on the market. In its present stage of development, to be successful, canneries must be operated on a large scale, with continuous supplies of different products to be canned in their season. Small canneries handling a single vegetable or fruit for a limited period only are at a great disadvantage.

Canning crops usually are grown under contract—a definite acreage to be planted at a certain time and the product delivered to the canner at a stated price subject to grade and quality. Contract prices are usually lower than market prices, but this is partly offset by the fact that the entire crop can be disposed of; expensive methods in production, packing, and shipping are eliminated, and no special efforts to hasten early maturity are necessary. The culture of canning crops is usually carried on in connection with other types of vegetable production or with general farming. While the returns to the grower are not likely to be high, canning crops are profitable when large yields can be produced at low cost.

Market Gardening. This term is generally applied to the production of a large number of crops on a relatively small scale for sale on a nearby market. This type of work has been carried on mainly in the vicinity of cities. Hence, the market gardener usually operates on high-priced land and must practice intensive methods in order to produce the most from a given area. Comparatively large investments are made in manures and in hand labor. Close planting and succession cropping are practiced—everything is done to conserve land area. The market gardener often operates on soil that is not especially suited for many of his crops, and he has only one set of climatic conditions for all of them. It is not likely that all vegetables will thrive in one place, although a considerable number may do so.

The market gardener plans his crops so as to have something to sell practically all the year round. This means that he has to become a master in the production of many different crops. Furthermore, he has to spend a considerable share of his time in the actual marketing, although many market gardeners are now eliminating this through marketing organizations, by selling through commission men, or by employing salesmen. The market gardener has an advantage in that he is in daily contact with his market and can regulate his operations to some extent according to market conditions. He is practically limited to a single market, however, and when that is oversupplied, he has no outlet for his produce. On the whole, market gardening offers good opportunities for profitable vegetable production, if proper attention is given to the location, the choice of crops, market demands, and sufficiently large-scale operation.

Truck Farming.—This term applies to the production of vegetables on a large scale at a more or less great distance from the market. Generally, one or only a few kinds of vegetables are grown, these being the crops best adapted to the soil and climate, and for which a favorable market condition may be expected to exist at the time the crops would normally be shipped from that district. This phase of vegetable production has shown the most rapid expansion in recent years, especially in the South and West. In these regions, rather remote from the main consuming centers, are found large areas of cheap land especially suited for growing certain crops. In many cases, crops can be matured in the South and West at seasons of the year when the chief markets are bare of locally grown produce, and thus favorable marketing conditions are created for the truck-farming districts. In other cases, some vegetables are shipped profitably from distant regions in the face of competition from local produce; for example, the shipment of western lettuce to the East throughout the year and of early potatoes from the South during the spring despite the presence of large quantities of "old" potatoes in the North.

Truck farming involves shipment in large quantities, usually in car lots, to distant markets. It is therefore dependent upon transportation facilities. The first extensive truck-farming area to be developed was in eastern Virginia, where water transportation to several large markets is possible. More recently, railroads have extended into areas suitable for truck farming, and this, together with the development of the refrigerator car, has stimulated the growth of truck farming. There is now a series of truck-farming districts along the Atlantic coast from southern Florida to Long Island. These districts grow about the same crops, but the time of maturity in the various districts becomes later from south to north, so that a succession of shipping seasons exists and prevents serious competition among the different districts. A similar series of districts is found in the Middle West, extending from the lower Rio Grande valley in Texas

to northern Minnesota. Other districts are developed on the Pacific coast, but they are more specialized as to crops grown and are less limited in their shipping seasons than the eastern districts. Knowledge of the chief producing areas for a particular crop, of the normal shipping season, and of the volume of shipments is fundamental to the organization of a profitable truck-farming business. The truck farmer seldom grows for any particular market; theoretically he has the markets of the whole country at his command. The marketing range is limited, however, by competition with other districts which are nearer the markets or have a superior quality of produce. The presence of locally grown produce must be considered also. Thus, because of competition from Florida and Mississippi, the Imperial Valley of California can seldom ship tomatoes farther east than Denver. Nor can southern California ship fall-crop tomatoes into the Middle West or East during August and September, because those sections are supplied from nearby sources. During this period, however, a demand exists in Texas and other southern states where the local crop is exhausted.

Status and Future.—Truck crop production at the present time is in a period of rapid expansion and rapid transition in methods, producing areas, marketing methods, and personnel. The growth of cities and the development of small-town markets during the past decade have enormously expanded the demand for vegetables. Modern knowledge of human nutrition and the broad dissemination of this information among the general public have emphasized the food value of vegetables and done much to increase the consumption of some crops, particularly spinach, tomatoes, carrots, lettuce, and rhubarb. For instance, spinach has increased from being a very minor crop 10 years ago to being one of the major crops for fresh use and for canning. Then, too, the extension of vegetable-growing areas has made it possible to supply the markets with most vegetables throughout the year and thus to increase consumption. Likewise, the increase in foreign elements of our population has increased the market demand for vegetables, for these people consume more vegetables than the older Americans.

Since 1920, agriculture in the United States has been more or less depressed. Vegetable production has felt this depression, which is due to over production, at various intervals and in various crops. Because of their perishable nature and because of the short time required to plant, mature, and market the crops, truck growing presents more violent alternations of over- and undersupply than do the "staple" farm crops, such as wheat or cotton, in which the marketing period can be extended over 2 or 3 years if necessary. There is no doubt, too, that vegetable production is sharing in the general ills of agriculture—especially high transportation rates, high cost of manufactured supplies, and unsatisfactory marketing methods. The widespread differences in prices received by the

grower and those paid by the consumer are probably more noticeable with vegetables than with other products, though this is partly necessitated by their perishable nature and the high cost of the risks involved in vegetable marketing. No doubt this condition will be alleviated to some extent by adoption of better marketing methods.

The main line of improvement, however, will come through the adoption of better methods of production, so that the grower can produce profitably yet sell his crops at prices no higher than those now prevailing. This means that soil and climatic factors will have to be considered very carefully in order to give the plant that environment most favorable for it. The study of the plants themselves, with a view of developing more logical methods of culture, becomes important. More careful consideration of the plants' nutrition and of methods of soil handling is necessary. This will, in many cases, involve greater expenditures for manures. More attention to seed selection, choice of varieties, and control of insects and diseases will greatly reduce the overhead costs in vegetable production. All this means simply the application of scientific principles—of making use of what is already known—in crop production. Science has advanced more rapidly than production practices have followed. There is yet much to learn, however, and it is still necessary for science to go ahead of purely practical considerations.

Vegetable production will become increasingly important in the United States as compared to other fields of agriculture as the country becomes more densely populated. We are no longer able to increase production by merely expanding and occupying new areas of virgin soil. In the future, increased production will be obtained by the growing of crops more intensively, as is now being done in many of the European and Asiatic countries. The period of lethargy and passiveness regarding the problems of the vegetable industry is almost at its end. There is now becoming evident an increased activity in the various fields of research on vegetable crops. To help solve these problems there will be required men who have sympathy for the industry, knowledge of production and marketing methods, and a firm foundation in the fundamental sciences. Vegetable crops have been grown from time immemorial, and they probably will continue to be grown as long as man inhabits the earth. As an industry, vegetable growing is as enduring as man himself.

PART I

GRAMINEAE

Many of the world's most important crop plants belong to the *Gramineae*. They are scattered widely over the earth and supply most of the food for the human family, as probably they supplied the principal food of the ancients and prehistoric man. Of this vast array of crop plants, a sub-species of maize known as sweet corn (*Zea mays saccharata*) is alone cultivated as a vegetable.

TRUCK CROP PLANTS

CHAPTER I

ZEA

Sweet corn is grown to some extent in every part of the United States. It is grown as a market crop and for canning. The geographical center of the sweet-corn belt lies somewhat north of that for field corn. This is due primarily to the ravages of the corn ear worm in the South. It is almost impossible to grow sweet corn for canning purposes where the corn earworm is a major pest. The prevailing high temperature in the South during the harvesting period also makes difficult the canning of a high-quality product.

Taxonomy.—Weatherwax (1923) gives the most generally accepted account of the genetic history of corn. He states that maize stands almost alone among the cultivated cereals whose wild prototype is unknown. A plant has never been found exhibiting relationships with maize. In both the vegetative and floral structures of maize, however, there are numerous rudimentary organs which, from their behavior during the development of the plant, are thought to be the remnants of parts that have ceased to function and not the forerunners of parts that are to be. Many of the abnormalities occurring in corn result from the functioning and development of these rudimentary organs.

The rudimentary organs and significant anomalies of the three genera, *Zea*, *Euchlaena*, and *Tripsacum* show a remarkable similarity in structural plan and furnish a basis for working out the true genetic relationships. It is thought that these three genera descended directly and independently from a common ancestor now extinct.

Weatherwax states that

> The common ancestor was probably a herbaceous perennial. Its branching culms arose in tufts from a mat of short rhizomes, and the ramifications branched again and again at all but the uppermost nodes. Diffuse panicles of paired spikelets terminated all the branches. Each spikelet had two perfect flowers. The pistil had two styles.
>
> Embodied in this species was a tendency toward specialization by the abortion of parts. This has found its best expression in the evolution of monoecism. The manner in which monoecism came about differentiated Tripsacum from Euchlaena and Zea. The latter two differed from each other in the manner of

the reduction of their panicles. With the adoption of the annual habit, the rhizomes disappeared, and the tufts of culms were reduced to a single axis, and its branches.

At the climax of evolution in maize, the process of abortion has eliminated all the lateral branches except that bearing the ear, and has left but two inflorescences.

History.—According to Sturtevant, sweet corn is one of the most modern of our garden vegetables. It was not known in New England until 1779. It is reported that a few ears were brought that year to Plymouth by one of the men in General Sullivan's expedition against the Indians, who had found it among the Indians on the border of the Susquehannah. Since that time, sweet corn has been disseminated throughout all of the civilized countries of the world. Only one variety was offered for sale by Thorburn in 1828. In 1881, 16 varieties were listed. Since the latter date, the number of varieties has increased manyfold.

Plant Characteristics

Roots.—In germination, a single primary root appears, but at the nodes of the stem just above, there soon arise whorls of secondary roots. Ten Eyck (1905) noted that the main growth was at first lateral and that most of these roots arise from the lower nodes of the stem. The roots that arise later and higher on the stem tend to grow almost directly downward. Some of them, however, take an intermediate course between the vertical and the horizontal. Weaver, *et al.* (1922), found that the lateral spread of roots on all sides of the plant was approximately 4 feet and that the maximum depth of penetration was 8.2 feet. The shallow part of the root system was more profusely branched than that more deeply situated. They state that the root system of a mature corn plant occupies, rather thoroughly, over 200 cubic feet of soil. They also show that the method of development of the root system varies somewhat with different soil conditions.

In a comparison of root systems of listed and level-planted corn 65 days after planting, Ten Eyck (1905) found that the "root crown" of the former is located fully 3 inches deeper in the soil and is less compact and fibrous. The lateral roots of listed corn extend from the nodes in an almost horizontal direction, while those from the level-planted corn arise near the surface and curve downward and outward. The average depth of penetration was greater in the case of the listed corn 65 days after planting; but after 125 days, the roots of the level-planted corn had penetrated to the same depth. There was also an increase in the root development near the surface in the listed corn.

Weaver (1925) studied the ratio of absorbing area (root area exclusive of root hairs) to the transpiring area (area of stem and both surfaces of

the leaves) of corn when plants were grown on soils of different moisture content. Two groups of plants were grown for 5 weeks in fertile-loam soil at water contents of 9 and 19 per cent, respectively, above the hygroscopic coefficient. In the wet soil, the area of the tops was 82 per cent that of the roots, *i.e.* the absorbing area was one and two-tenths times that of the transpiring area. In the drier soil, the area of the tops was only 46 per cent that of the roots, or the absorbing area was two and two-tenths times the transpiring area.

Buttress Roots.—When the stem is elongating and usually before the tassel appears, one or more nodes above the ground give rise to a whorl of roots thicker and stronger than those arising below ground. They curve outward and downward and penetrate the soil. They function as anchors, or props, for the stem and also as absorptive organs. According to Weatherwax (1925), in the aerial portion of these roots, the sclerenchyma is well developed and the epidermis is silicified. The aerial portion is not branched, but below ground it is much branched.

Stems.—Weatherwax states that when a corn seedling is 5 to 10 inches high, all the leaves, buds, and internodes and the main branches of the terminal inflorescence are often already formed. A young internode increases in both length and thickness for a time. Elongation of the internode, however, continues for a considerable time after the ultimate diameter has been reached. The oldest tissue is at the upper end of each internode. A layer of meristematic tissue at the lower end of the internode is responsible for increase in length. Even after the normal growth stops, if the stem is brought to a position out of the vertical, the cells on the lower side of this meristematic region start to grow again.

According to Weatherwax (1925):

> The upper internodes are straight and nearly cylindrical. The buds at the upper nodes are small and poorly developed, or sometimes represented by only a meristematic region. The internode immediately above each ear is deeply grooved on one side and bent concave to the ear. The internodes below the ear are straight but often flattened; a groove on one side of each of these contains the bud. These grooves are alternately arranged on succeeding internodes, corresponding to the alternate arrangement of the leaves and buds. The walls of the epidermal cells are hardened with deposits of silica. Below the epidermis are several layers of sclerenchymatized cells. The internodes of the stem are solid with pith. This pith is traversed by many scattered parallel-running vascular strands which give tensile strength and serve as conductive tissue.

"Suckers" are secondary stems which arise from the lower nodes at or near the soil surface.

Leaves.—The corn leaf has three distinct parts—sheath, blade, and ligule. The sheath arises at the node, and it is closely wrapped about

the greater length of the internode above which it is attached. The blade is long and flat. A large midrib extends the full length of the blade, and parallel to it run numerous smaller veins. The ligule which is attached at the top of the sheath fits tightly about the stem. It serves

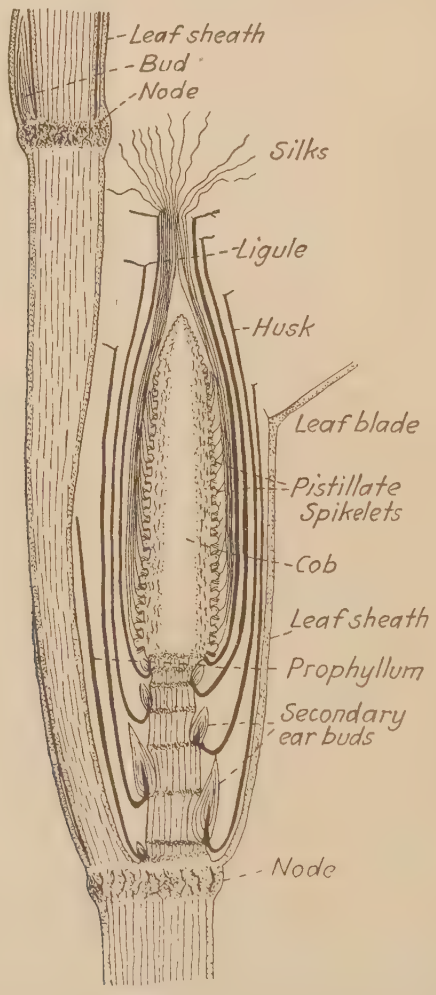

FIG. 1.—Diagram of longitudinal section of ear-bearing branch. (*Redrawn from Weatherwax* 1923.)

to prevent the entrance of water between the sheath and stem. Histologically, the leaf and sheath are very similar.

The stomata are more numerous on the lower than on the upper surface. Kiesselbach (1916) reports 49,665 stomata per square inch in the upper epidermis and 59,985 per square inch in the lower epidermis. The stomatal aperatures in the epidermis of the leaf occupy, when open,

about 0.76 per cent of its area. The stomata were found to be nearly closed at night and also when the leaves were wilted.

On the upper side of the leaf, there are groups of wedge-shaped, hygroscopic cells. Usually at night, and during the cooler part of the day, and at other times when transpiration is not excessive, these cells are turgid and cause the leaf to remain flattened. When the loss of water from the plants exceeds the amount being absorbed, they lose their turgidity and become smaller. This causes a narrowing of the upper epidermis and an inward rolling of the leaf. This rolling protects the upper epidermis and a portion of the lower epidermis from excessive transpiration, by exposing a smaller area and thereby lessening the evaporating surface.

Inflorescences.—As a rule, the corn plant is monoecious. The staminate inflorescence, or "tassel," is terminal. The central axis as well as the lateral branches of the tassel are spike-like. The spikelets are almost always arranged in pairs. In each pair, one spikelet is sessile and the other, pediceled. The central spike usually has four or more rows of spikelets in pairs, while the lateral branches usually have two rows of spikelets in pairs. The pistillate inflorescence is borne at the terminal end of one of the lateral branches near the center of the main stem. These branches are very short, due to the shortening of the internodes. From each node of the ear-bearing branch there arises a single leaf, but the blades of these are usually lacking or much reduced in size. Due to the closeness of the nodes, the sheaths overlap one another and form the so-called "husks" enclosing the ear. The pistillate spikelets are borne on the central axis in longitudinal rows, in pairs. Each pair of spikelets thus produces two rows of grains, giving the paired effect common in most varieties of corn.

Pistillate Spikelet.—The pistillate spikelet bears two flowers, but in most cases one of these aborts, so that in each spikelet there is only one functional flower. Each flower has a pistil and three rudimentary stamens. Each flower is subtended by a lemma (flowering glume). Between the two flowers are located the two palets. According to Weatherwax (1923), the two lodicules, which alternate with the stamens, are probably the metamorphosed remnants of a perianth; in the early stages of growth, they are present in both flowers, but those of the sterile flower are usually much better developed.

Miller (1920) states that the tip of a very young cob shows only meristematic cells. A short distance back of the tip, numerous projections appear. Each projection is a primordium that will develop into a pair of spikelets. These primordia divide equally, each half producing a spikelet. The lower empty glume is the first to differentiate and is soon followed by the upper empty glume. The primordia of the two lemmas are the next to appear. Soon after, or frequently at the same time, the rudiments of the sterile flower and of the stamens in the fertile flower

appear. The palet of the fertile flower at this time also begins to show differentiation, but the palet of the sterile flower does not appear until considerably later.

The primordium of the ovary wall of the fertile flower appears shortly after those of the palet and stamens of the fertile flower. The carpel grows unevenly, so that when the side adjacent to the lemma extends

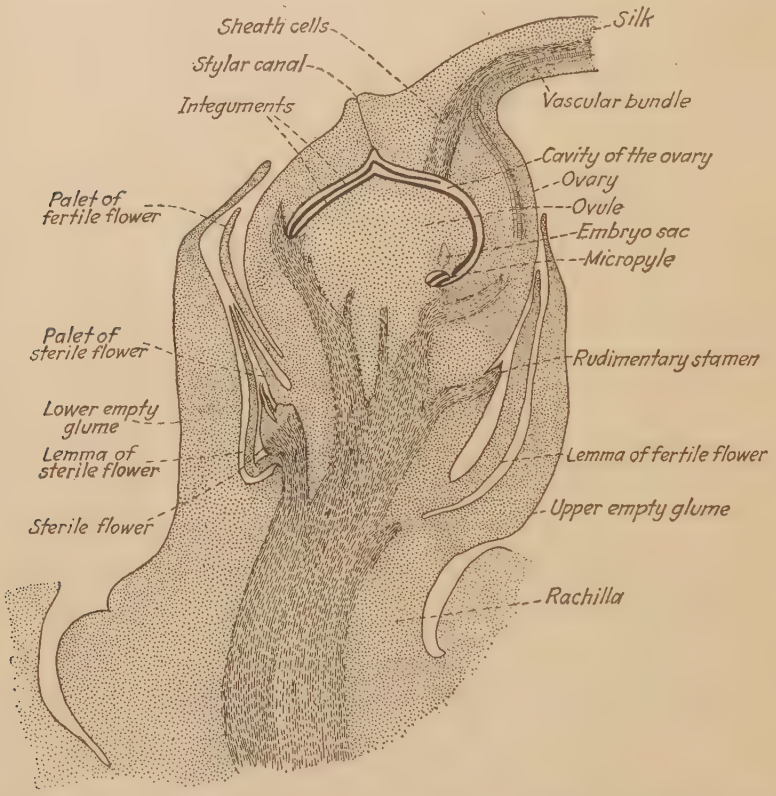

Fig. 2.—Diagram of longitudinal section of pistillate spikelet. (*Redrawn from Miller* 1920.)

almost one-third around the young ovule, the opposite side has scarcely begun to develop. The meristematic cells on the upper part of the carpel later elongate very rapidly to form the silk. As the silk elongates, the wall of the ovary grows up around the ovule, but a small opening—the stylar canal—remains near the top.

About the time the silk begins to elongate, the side of the ovule adjacent to the palet grows more rapidly than the opposite side, causing the ovule to become inverted.

Oögenesis.—About the time the ovule begins to invert, the megaspore mother cell is differentiated. According to Weatherwax, after the

heterotypic division of the megaspore mother cell, a wall divides the two daughter cells. The inner one of these divides again, producing two megaspores. All but the innermost megaspore disorganize.

The functioning megaspore, or embryo sac, enlarges, absorbing the disorganizing sporogenous cells and nucellar tissue. The nucleus divides, and the two daughter nuclei move to opposite poles of the cell, where they again undergo division. One of the nuclei at the micropylar end of the cell divides to form the two synergids, and the other divides, giving

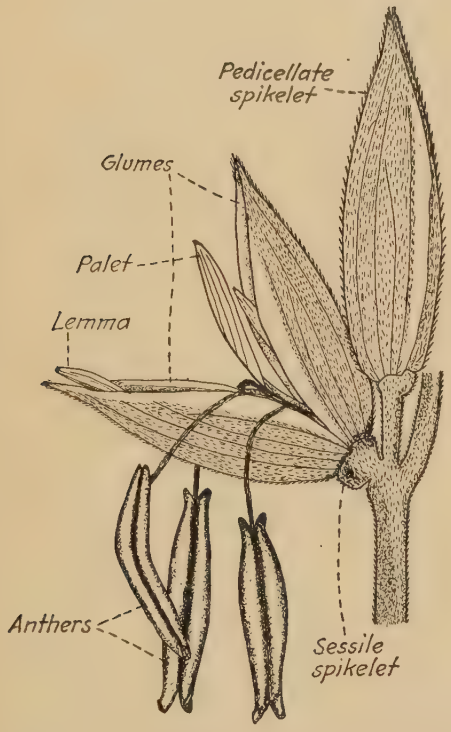

FIG. 3.—A pair of staminate spikelets. (*Redrawn from Weatherwax* 1923.)

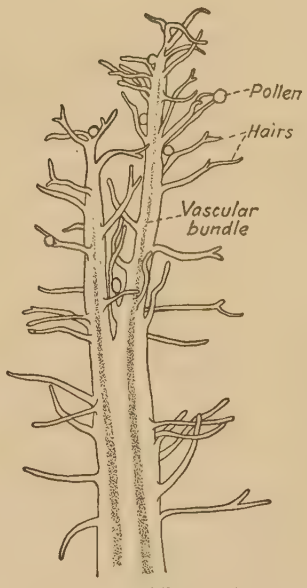

FIG. 4.—Tip of silk with stigmatic hairs and pollen grains. (*Redrawn from Miller* 1920.)

rise to the egg nucleus and one polar nucleus. Meanwhile, at the other end of the sac one nucleus has divided to form two antipodal nuclei; and the other, to form one antipodal and one polar nucleus. The two polar nuclei move toward the center of the sac. The antipodal cells continue to divide, so that, by anthesis, there are 24 to 36 present.

Silk.—According to Weatherwax, the silk is a solid, flattened organ, divided in two for some distance from the tip. The whole length of the silk is traversed by two vascular bundles. The hairs of the silk have a

longitudinal canal through the middle. The silk is receptive to pollen to within 1 or 2 inches of the ovary.

According to Kiesselbach (1922), the silks are receptive over a considerable period of time. They are receptive before they have emerged from the husks and for 2 weeks thereafter. They continue to grow in length for some time, if pollen is withheld.

Staminate Spikelet.—At the base of the staminate spikelet are two glumes which are overlapping previous to anthesis. They enclose two fertile male flowers—the lemmas and the palets. Each male flower produces three stamens and one rudimentary pistil.

Anthesis in the Tassel.—Weatherwax (1925) states that anthesis begins at some distance from the end of the central spike and proceeds both upward and downward. A little later, the spikelets near the ends of the uppermost branches of the tassel begin to open, and a wave of maturity passes down all the rachids at the same time. The oldest flowers are in the upper and the youngest in the lower part of the tassel. The upper flower of a spikelet usually reaches maturity a few days before the lower. Before the upper flowers of the lowest spikelets are shedding pollen, the lower flowers of the upper ones have begun to open, and there is a second wave of maturity. The flowering of a single tassel may extend over a period of several days to 2 weeks, depending upon atmospheric conditions and the size of the tassel. Cool weather prolongs the blossoming period.

Pollen.—The pollen grains are round to oval and do not adhere to one another. Golden Bantam sweet-corn pollen was found by Knowlton (1922) to measure 106 to 120 microns. There are from one to three germ pores. From 15 to 20 per cent of the weight of the fresh substance is starch. A detailed study of the chemical composition of corn pollen has been made by Anderson and Kulp (1923). According to Weatherwax (1923), the mature pollen grain contains two fully developed sperms.

During hot, dry weather, the pollen is often killed, and a good set of seed is not obtained. Knowlton (1922) found that the moisture content of pollen ranged from 50 to 60 per cent, depending on the conditions under which the plant had been grown. It remained viable longest under conditions of moderately low temperatures (5 to 10°C.) and moderately high humidities (50 to 80 per cent). The maximum duration of viability was from 70 to 80 hours. Under normal conditions, the death of corn pollen is caused by desiccation, but, since life is not greatly prolonged by storage under conditions which retard evaporation, moisture is not the only important factor. The grains, however, may lose 40 to 50 per cent of their water without materially impairing their viability.

Pollination.—Wind and gravity are the chief agencies in pollen dissemination; consequently cross-pollination is the rule. Kiesselbach (1922) planted a white (recessive) variety of field corn in a field of yellow (dominant) corn. The white corn was distributed systematically 60 hills

apart. The per cent of self-fertilization could be determined by counting the number of white kernels on the mature ear. All cross-fertilized kernels on the white variety would be yellow. It was found that only 0.7 per cent of the kernels were actually selfed.

In an 8-year yield test, seed selected from detasseled rows in a seed plot yielded 0.6 per cent more than did seed taken from normally field-pollinated rows. As selfing reduces the yield approximately one-third in the first generation, this also indicates that no extensive self-fertilization takes place and that very little is gained by selecting seed from detasseled plants. The great preponderance of foreign pollen almost entirely prevents self-pollination. Protandry, common in most varieties, helps to prevent self-pollination. Kiesselbach (1922) also determined the yields separately

> . . . for the detasseled and not detasseled rows in the seed plot for the purpose of determining the immediate effect of detasseling upon the current crop. As an average for the 8 years the plots from which all the tassels were removed yielded 43.6 bushels per acre as compared with 42.9 bushels for the normal corn.

According to Weatherwax (1925), one anther produces about 2,500 pollen grains; and a single spikelet, about 15,000. The ratio of staminate spikelets to pistillate is about 10:1. As a pistillate spikelet requires but a single pollen grain, the ratio of male gametophytes to female may therefore be as high as 150,000:1.

Germination and Growth of Pollen Tube.—Knowlton (1922) obtained the best germination by use of a solution containing 15 per cent cane sugar and 0.7 per cent agar. According to Miller (1920), the pollen tube emerges from the germ pore a few hours after the grain lodges on the silk. Shortly afterward, the tube enters the main body of the silk, usually by way of one of the silk hairs. The pollen tube with its contents travels to the egg along the sheath cells of the bundles of the silk. It is difficult to locate the pollen tube even a short distance back to its growing region; it is probably absorbed by the surrounding cells. The growing region of the tube is probably nourished by the sheath cells. The pollen tube pushes its way between the sheath-like cells that extend from the bundle of the silk to the cavity of the ovary; it passes through the micropyle and then through the cells of the ovule to the embryo sac. A number of pollen tubes may start down each silk, but these become fewer and fewer, and probably only one reaches the ovule. Growth of the pollen tubes is very rapid; under ordinary conditions, they reach the embryo sacs of all the ovules on the ear in 24 hours after pollination. In order to do this, the longest tubes must grow in that time approximately 6 inches, a distance that equals 1,500 times the diameter of the pollen grain.

Fertilization.—According to Miller (1920), the pollen tube extends into the embryo sac until the tip is near the polar nuclei. The wall of the tube is dissolved, liberating the nuclei. One sperm nucleus fuses with the egg and the other with one of the polar nuclei. The polar nuclei fuse at the time the sperm nucleus enters one of them, or shortly afterward.

Embryo Development.—Weatherwax (1923) states that several hours after fertilization the zygote has been divided by a transverse wall into a small upper cell and a large, vacuolate, lower cell. The upper cell develops into the embryo, while from the lower cell the suspensor arises. The coleoptile is the first part of the plumule to appear. It arises first as an open sheath; but later, the edges are completely united. Inside of this sheath, the primordia of several foliage leaves and sometimes one or more axillary buds are developed before the maturity of the seed. Next in order, the primary root is differentiated from the body of the axis of the embryo between the plumule and suspensor. From the tissue left surrounding the root proper, the root cap is later formed, and the remaining sheathing portion constitutes the coleorhiza. Three or more secondary roots are later differentiated from the central cylinder of the axis of the embryo near the point of attachment of the cotyledon. From the cortex, a cap is split off for each root. The suspensor develops in thickness and length and keeps the cotyledon in contact with the endosperm.

Endosperm.—In double fertilization, one of the male nuclei unites with the egg nucleus, while the other male nucleus unites with the two polar nuclei. The union of one male nucleus with the two polar nuclei of the maternal side is often referred to as "triple fusion." Each of the polar nuclei and also the male nucleus carry ten—the haploid number of chromosomes. The endosperm nucleus then contains the triploid number of chromosomes.

The term "xenia" is applied to the phenomenon in which some character of the male is visible in the endosperm of the seed as a result of cross-pollination. For example, when a white variety is the female parent and a yellow variety is the male parent, all of the endosperm in the grains will be pale yellow. The endosperm possesses the dominant yellow of the male parent, even though the white-endosperm parent contributes two-thirds of the hereditary material. If the reciprocal cross is made and the yellow endosperm variety is used as the female parent, all the kernels will again be yellow. In each case, the factor for yellow is dominant, although incompletely so. According to Weatherwax (1923):

> . . . xenia may be expected to occur: (1) when the female parent bears the recessive, and the male the dominant, of a pair of endosperm factors, neither being accompanied by an inhibiting factor for the dominant; (2) when the female parent bears a dominant endosperm factor, or combination of factors, whose action is capable of being inhibited by a factor carried by the male; or (3) when

the male and female parents, respectively, bear latent complementary factors whose interaction is necessary for the production of a definite effect on the endosperm.

According to Miller (1920), the endosperm nucleus begins to divide almost immediately after fertilization. In 10 to 12 hours, the nuclei of the endosperm may number 20 to 30. These endosperm nuclei are arranged around the periphery of the embryo sac. At this stage, the egg nucleus has just undergone its first division. Within 36 hours after fertilization, the endosperm nuclei completely fill the embryo sac. Endosperm growth keeps pace with the enlargement of the sac.

Mature Seed.—The outer, dry covering of a kernel of corn consists of the pericarp and testa combined. The remnant of silk can be seen at the end opposite the point of attachment to the cob. Most of the seed is endosperm. Imbedded in one side of the endosperm and in contact with the seed coat is the embryo. The plumule is the bud from which the stem and leaves develop; it is completely enclosed in the coleoptile or plumule sheath. The radicle consists of the primary root and its cap and the enclosing coleorhiza, or root sheath. The cotyledon, or first leaf, of the embryo is attached laterally to the central axis. The portion of the cotyledon in contact with the endosperm is the scutellum. The middle portion of the embryonal axis to which the cotyledon is attached is the stem of the embryo; arising from it are the primordia of two or more secondary roots. In field corn, Hopkins (1898) removed the germ, or embryo, and found that it was only 12 per cent of the dry weight of the kernel but contained nearly twice as much mineral matter as all of the rest of the kernel and three or four times as much oil.

Climatic and Soil Requirements

For its best development, corn requires a large amount of sunshine and moderately high temperatures. Sweet corn for roasting ears can be grown successfully farther north than field corn because it is harvested before it matures. The long days of summer in the North, with their accompanying long light duration, compensate to a certain extent for the short growing season.

Temperature.—While warm days and warm nights produce the best growth, nevertheless for the canning crop, planting should be regulated so that the harvesting season will come when the temperature is cool. Then the rate of ripening is slower and the kernels are in the best edible condition longer than under high temperature conditions. The opportunity to get the corn harvested in the best canning stage is greater when the temperatures are low during the harvesting season.

Water Requirement and Transpiration.—The water requirement of a plant is judged by the number of units of water that the plant must

absorb in order to produce one unit of dry matter. The water requirement is usually expressed in pounds and determined by measuring the amount of water lost from the plant by transpiration. Kiesselbach (1916) found the water requirements of 11 different varieties of corn to range from 230 to 296 pounds. The water lost by transpiration was about one-third of the evaporation from a free water surface of the same area. Maximum transpiration occurs between 1 and 3 p.m. Transpiration increases up to this time from early morning and then decreases until late in the evening. Under conditions favoring rapid transpiration, a plant may lose 10 pounds of water during 24 hours. As the fertility of the soil increases, within certain limits, the number of pounds of water absorbed from the soil per plant increases, but the water requirement per pound of dry matter decreases. On the other hand, factors which retard growth result in a relatively high water requirement, because water is being used without a normal increase in dry matter.

Manuring.—Truog, *et al.* (1925), in Wisconsin, recommend that corn be grown in a definite system of crop rotation and that the basic supply of K and P for all the crops in the rotation be maintained by applications of manure and commercial fertilizers and the N supply, by use of manure and the growing of legumes. Besides this residual supply of fertilizer, it is often desirable in the case of soils of low production to give the corn crop special fertilization in the row. In the check, or hill, method of planting, the best results are obtained when the application at planting time is spread in a 4 by 8 inch band, ½ to ¾ inch above the kernels. The fertilizer drills can be adjusted to secure this method of distribution. After the same manner, 150 to 200 pounds can be added to the acre, except on sandy soils where smaller amounts must be used to avoid injury. If the seed and fertilizer are both drilled, 300 to 400 pounds to the acre may be used with safety. Fertilizer should never come in contact with the seed; if there is too high a concentration of salt in the soil solution surrounding the seed, sufficient water cannot be absorbed to obtain good germination. Injury from this cause is more pronounced on sandy soils than on peat and heavier soils and also more pronounced at low than at high moisture contents.

In the Wisconsin experiments, the 2:12:2 and 3:10:4 mixtures gave the best results of those used at planting time. The source of N giving the best results when used at time of planting was ammonium sulphate; ammonium sulphate leaches to a less extent than sodium nitrate. For top dressing after the crop is well started, sodium nitrate is best, as it is easily dissolved and carried to the roots by rain.

The same formula, rate, and method of application will not give equally good results on all types of soil under different climatic conditions. It will be necessary for each individual grower to determine the best combination to use for his local conditions.

Cultural and Handling Methods

Rate of Planting.—The rate of planting varies with the soil, climate, and the variety used. Within certain limits, however, the rate of seeding does not have a marked effect on the yield. This is well illustrated by experiments conducted at the Nebraska Experiment Station by Montgomery (1909). Hoague's Yellow Dent field corn was planted in hills 3 feet 8 inches apart each way. From one to five kernels were planted in each hill. The results obtained for a period of 6 years is given in table 1. Similar results were obtained by Kiesselbach (1922).

Table 1.—Average Results from Planting Corn at Various Rates for 6 Years 1903–1908

(*Montgomery*, 1909)

Plants per hill	Yield per acre, bushels	Average weight of ear, ounces	Number of ears per 100 plants	Number of tillers per 100 plants	Two-eared plants per row[1]	Barren plants per row	Yield of stover per acre, pounds
1	48.3	10.5	161	138	13.3	3.0	
2	67.7	10.6	115	60	4.9	4.8	5,984
3	75.5	9.4	95	25	2.4	6.9	5,972
4	76.7	8.2	82	10	0.8	8.3	6,692
5	76.3	7.4	77	3	1.1	10.8	6,969

[1] Four-year averages.

The yield of grain per acre was about the same, regardless of whether three, four, or five kernels were planted to the hill. As the rate of planting increased, there was a decrease in the average weight of the ear, the number of ears per plant, the number of tillers per plant, and the relative number of plants bearing two ears. There was an increase in the yield of fodder per acre and in the relative number of barren plants. Two plants per hill produced about 90 per cent as much as three plants, and one plant per hill produced 64 per cent as much grain as three plants to the hill. The increased yield per plant from the hills with one to two plants is due mainly to the production of larger ears and to an increased number of ear-bearing tillers. Under the conditions of the Nebraska experiment, three plants per hill are regarded as a full stand. Under a different set of conditions, however, the best results might be obtained from a different rate of planting.

Kiesselbach (1922) compared over a 5-year period the effect upon the yield of grain per acre of varied distribution of plants in a field. The total number of plants in adjacent hills differed: "The methods of distribution compared were as follows: (1) All hills with uniformly three plants, (2) alternating hills with two and four plants, (3) alternating hills with one,

three, and five plants, (4) alternating hills with one, two, three, four, and five plants." Methods (1), (2), and (4) gave about the same yield, but method (3) gave slightly less. The conclusion reached was that "corn plants, of the larger varieties, at least, draw upon the soil fertility and moisture for such a distance that considerable irregularity in stand may exist without markedly affecting the yield."

Depth of Planting.—Corn is usually planted 1 to 3 inches deep, depending on the type of soil. The main object is to plant sufficiently deep to be certain of plenty of moisture for germination. The root system does not establish itself at a greater depth in the soil if planted deep than if planted shallow.

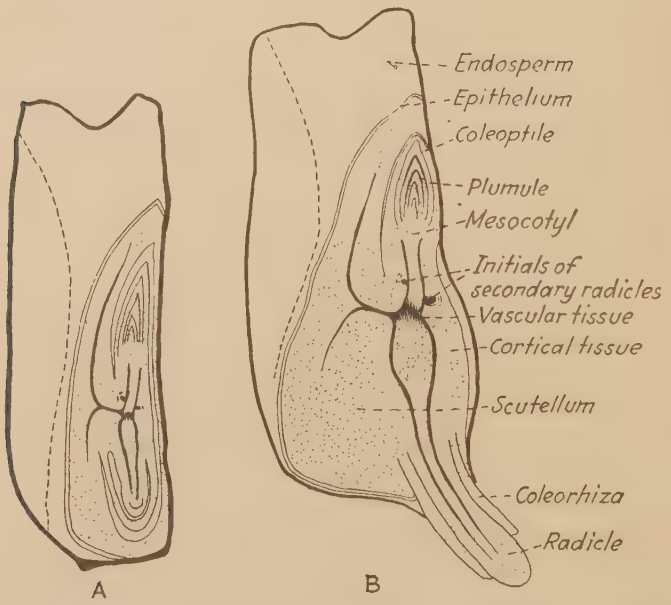

FIG. 5.—A. Longitudinal section of a dry grain of corn. B. Longitudinal section of grain after about 48 hours germination. (*Redrawn from Toole* 1924.)

Germination.—According to Toole (1924), the first indication of germination is the imbibition of water by all the cells of the grain until they are turgid. There seem to be no actual enlargements of the cell walls or any chemical change. Somewhat later, the cells of the coleorhiza enlarge; this breaks the fruit coat, and the coleorhiza then protrudes about 2 millimeters but does not develop further. A few hours later, the radicle breaks through the surrounding sheath. When the radicle is about 1 to 2 centimeters long, the mesocotyl begins to elongate. This causes the fruit coat to be ruptured by the coleoptile. The latter remains intact, enclosing the plumule, until the surface of the soil has been reached.

It is brought to the surface primarily as a result of the growth and elongation of the mesocotyl. The coleoptile protects the young leaves and helps them bore through to the surface. If the grain of corn is planted too deep, the leaves break through the surrounding sheath before the surface is reached, and, as a result, the seedling usually dies.

Accompanying the elongation of the mesocotyl, there is also a development of the secondary roots. Shortly after the initial growth of the radicle, there is an elongation of the cells of the scutellum which abut on the endosperm. These cells produce the enzymes which digest the endosperm, which is in turn transferred to the growing parts of the embryo. The scutellum gradually advances upon the endosperm as digestion takes place.

Germination may be said to be over when the young roots start to absorb moisture and salts from the soil and the leaves reach the surface, expand, and carry on photosynthesis.

Cultivation.—Numerous experiments show almost conclusively that the main object in the cultivation of corn is the destruction of weeds, which use up the soil water and the available mineral elements essential for plant growth. Cates and Cox (1912), of the United States Department of Agriculture, in a very extensive project covering 6 years, compared the yield of corn from plants grown where the weeds were kept under control by cultivation with those grown where the weeds were destroyed by scraping. The results of 125 tests under a variety of conditions showed that 99.1 per cent as much grain was produced on the scraped plots as on the cultivated. Cultivation should be shallow, as many of the roots of the corn plant are near the surface. The roots are nearer the surface next to the plant than midway between the rows. Listed corn can be cultivated more deeply than surface-planted, at least during the early part of the season. It is doubtful if cultivation is profitable beyond that needed for the control of weeds.

Suckering.—Formerly, "suckering," or the removal of tillers from the base of the plant, was a common practice. This practice is still carried on in some sections; but in most regions, it has not been found to be profitable. Thompson (1926) conducted suckering experiments in New York on Stowell's Evergreen, spaced 3 by 3 feet, and Golden Bantam, spaced 2 by 3 feet. The plants were thinned to three in a hill. The methods of handling were as follows:

A. Suckers were allowed to grow (check).

B. Suckers were removed when the plants were from 12 to 18 inches high. Suckers appearing later were allowed to remain.

C. Suckers were removed as in B; other suckers were removed as they appeared during the season.

D. Suckers were removed when the plants began to tassel.

Table 2 summarizes the results obtained over a 5-year period.

TABLE 2.—INFLUENCE OF SUCKERING SWEET CORN IN YIELD OF EARS AND STOVER (*Thompson*, 1926)

Treatment	Total yield of marketable ears		First picking of marketable ears		Total yield of grade No. 1 ears		Average weight of ears, ounces		Yield of stover per acre, pounds
	Number	Weight in pounds	Number	Weight in pounds	Number	Weight in pounds	Total marketable	grade No. 1	
Golden Bantam									
A	1,086	400.9	303	118.1	803	326.2	5.90	6.50	9,525
B	1,042	387.9	324	127.7	783	313.6	5.95	6.42	7,385
C	1,024	387.9	319	126.2	781	322.1	6.06	6.61	6,960
D	951	344.7	283	113.3	738	299.8	5.79	6.50	6,502
Stowell's Evergreen									
A	692	508.1	290	227.4	498	412.2	11.74	13.25	10,873
B	672	488.9	303	237.2	482	394.9	11.63	13.10	9,455
C	676	499.1	327	252.8	492	402.1	11.81	13.07	10,000
D	650	476.1	289	228.4	470	382.0	11.71	13.01	9,211

Under the conditions of this experiment and with the varieties used, the unsuckered plants gave the highest total yield, although there is little difference between plots A, B, and C. There is also very little difference between the latter three plots in size of ear and earliness. On all the suckered plots, the yield of stover was reduced. Late suckering reduced both the yield of ears and stover more than early suckering.

Removal of suckers is probably not necessary or profitable in most of the large sweet-corn-producing districts. While, however, there are no published records of suckering experiments on the Pacific coast, it is well known that if the suckers are not removed there, marketable ears of sweet corn are often not produced. Conclusions drawn from suckering experiments conducted in the Middle West and in the East cannot be made to apply to districts where the climatic conditions are very different. There is a considerable difference among varieties and strains in the tillering habit; this difference has been recorded by many investigators.

RIPENING

Chemical Changes in Sweet Corn during Ripening.—Appleman and Eaton (1921) studied the chemical changes taking place in the kernels of Stowell's Evergreen during the ripening period. Ears of the same age were selected for study. The first samples were collected on Aug. 3 when the selected ears were in the pre-milk stage. Succeeding samples were collected at 2-day intervals. Table 3 gives the results of the analyses.

TABLE 3.—CHANGES IN COMPOSITION OF SWEET CORN DURING RIPENING. PER CENT OF DRY WEIGHT

(*Appleman and Eaton*, 1921)

Date	Starch	Cane sugar	Reducing sugars	Fat	Crude fiber	Total nitrogen	Protein, total nitrogen times 6.25
Aug. 3	18.36	19.55	20.07	2.97	7.92	3.33	20.81
5	25.20	21.85	13.93	4.04	6.37	3.08	19.25
7	35.73	24.57	9.45	3.99	4.63	2.45	15.31
9	45.42	18.75	5.43	4.44	2.58	2.09	13.06
11	56.89	11.59	3.01	4.81	2.62	2.14	13.37
13	57.23	9.55	2.64	5.25	2.81	2.01	12.56
15	58.91	8.32	2.24	5.05	2.35	2.03	12.70
17	59.15	7.86	1.97	5.01	2.59	2.10	13.12
19	60.41	5.85	1.77	6.01	2.30	2.20	13.75

The chief changes in the solids during ripening are the loss of sugars and the increase in starch. At first, the reducing sugars predominate, but these decrease very rapidly in amount as ripening proceeds. The percentage of cane sugar increases, reaches a maximum, and then decreases. The highest percentage of sugar was present when the first samples were collected. The kernels are sweetest, however, when the percentage of cane sugar is highest; this is because cane sugar is much sweeter than the reducing sugars. Starch is formed and stored in large amounts in the kernels throughout the ripening period. It is probably synthesized from the sugars stored in the cob and stem. When ripe, the kernels had 60.41 per cent starch, 5.85 per cent cane sugar, and 1.77 per cent reducing sugars. Appleman and Eaton (1921) use the term "ripe" as being that time "when the growth of the kernel ceases and the chemical changes in the corn have nearly attained equilibrium positions—that is, it is ripe at the time after which the ratios of the various constituents change very slowly and very little." The later changes, which consists mainly in the loss of water, are spoken of as the maturing processes. There is a decrease in the percentage of crude fiber, total N, and protein N during the early stages of ripening. There appears to be a rather irregular, although definite, increase in the percentage of fat throughout the ripening period.

Influence of Temperature on Rate of Ripening.—Appleman and Eaton (1921) determined the influence of temperature on the rate of ripening in Maryland. One crop was planted early so that it would ripen during August when the temperature was high; a later planting ripened during the fall when the days were cool. As previously shown, the chief changes occurring during ripening are decrease in percentage of sugar and increase in percentage of starch. Consequently, the best measure to use in determining the rate of ripening under different temperature conditions is the

rate of decrease in the ratio of total sugar to starch. The first samples of each planting were collected for analysis when they were in the same stage of development. Samples were collected thereafter every second day for a period of 15 days. Table 4 gives the changes in percentage of moisture, total sugar, starch, and the sugar-starch ratio for both the early and late plantings.

TABLE 4.—COMPARISON OF EARLY AND LATE CROPS OF SWEET CORN IN RESPECT TO CHANGES IN PERCENTAGE COMPOSITION IN EQUAL LENGTHS OF TIME. PER CENT OF FRESH WEIGHT

(*Appleman and Eaton*, 1921)

Time from first examination, days	Early crop				Late crop			
	Moisture	Total sugars	Starch	Ratio of sugar to starch	Moisture	Total sugars	Starch	Ratio of sugar to starch
0	86.55	5.39	2.47	2.187	88.27	6.13	2.72	2.300
2	84.21	5.90	3.98	1.544	88.83	5.69	2.32	2.459
4	80.63	6.89	6.92	0.868	86.97	5.78	2.86	2.168
6	75.89	6.09	10.95(*a*)	0.556	85.56	5.53	3.39	1.747
8	72.05	4.21	15.90	0.264	85.21	5.56	3.85	1.448
10	70.47	3.75	16.93	0.219	83.80	6.30	5.48	1.164
12	67.78	3.50	18.98	0.183	81.56	5.62	6.90	0.879
14	64.98	3.55	20.42	0.170	79.26	5.26	8.71	0.673
15	64.98	3.02	20.94	0.149	77.69	5.08	10.09(*b*)	0.500

(*a*) Same stage of ripening as late crop on fifteenth day.
(*b*) Same stage of ripening as early drop on sixth day.

The sugar-starch ratio shows that it took the late planting 15 days to reach the same stage of ripening as that attained by the early planting in 6 days. The rate of ripening was two and one-half times as fast in the early crop as in the late crop. The ears ripening in the fall would be in the best edible condition two and one-half times as long as those ripening in the summer. There is consequently a better chance of getting corn harvested when it is in the best edible condition if planted so ripening will occur in the fall. The factor most responsible for this difference in rate of ripening is temperature. The average of the hourly mean temperatures for the ripening period of the early crop was 28.3°C. while that for the late crop was 18.3°C.

Culpepper and Magoon (1924) state that the amount and nature of the sugars affect the sweetness of the canned product, while the amount and nature of the polysaccharides affect its consistency. Toughness increases with age. There is little difference in toughness between different varieties if kernels are of the same age. Toughness cannot be masked; it lowers the quality of canned corn and is probably the most important factor determining edibility.

Influence of Temperature on the Chemical Changes within the Kernel after Harvest.—Appleman and Arthur (1919) studied the rate of change of sugars in the kernels after the ears had been separated from the stalk. Ears were picked when they were in the milk stage. At this time they are probably in the best edible condition. They were stored at 0, 5, 10, 15, 20, 30, and 40°C. Table 5 shows the percentage loss of sugars at the different temperatures over a 4-day period.

TABLE 5.—SUGAR LOSS FROM GREEN SWEET CORN DURING DIFFERENT PERIODS OF STORAGE AT DIFFERENT TEMPERATURES, EXPRESSED AS PERCENTAGES OF THE SAME INITIAL SUGAR AT ALL TEMPERATURES

(*Appleman and Arthur*, 1919)

Number of hours in storage, Centigrade	0°	10°	20°	30°	40°
			Total sugar		
0	Per cent	Per cent	Per cent	Per cent	Per cent
24	8.12	16.98	25.61	50.28	45.79
48	14.51	27.95	45.73	57.09	60.15
72	18.03	38.71	55.50	59.00	62.16
96	22.00	49.22	62.10	61.84	
			Sucrose		
24	3.51	20.78	31.05	59.42	51.03
48	10.39	37.49	56.12	66.76	64.68
72	15.08	47.46	64.22	68.55	69.24
96	21.35	60.54	70.16	70.19	
			Free-reducing substances, as invert sugar		
24	7.58	9.26	14.72	29.96	33.48
48	13.61	10.52	28.84	36.19	49.76
72	14.62	16.71	40.79	39.74	49.76
96	16.97	23.33	45.65	43.19	

It can be seen by referring to Table 5, that sugar is lost from the kernels regardless of the storage temperature. The rate of loss, however, is much more rapid at the higher than at the lower temperatures and is most rapid when first removed from the stalk. According to Appleman and Arthur, the depletion of sugar "does not proceed at a uniform rate but becomes slower and slower until finally the loss of sugar ceases when the initial total sugar has decreased about 62 per cent and the sucrose about 70 per cent." There still remain about 0.7 per cent sucrose and 0.8 per cent reducing sugars when depletion of the sugars ceases. This means

only that a point has been reached in which the rate of sugar formation approximates the rate of sugar loss. After equilibrium is reached, there must be about as much sugar formed as a result of starch hydrolysis as there is sugar lost because of condensation to starch. Raising the temperature merely hastens the attainment of the equilibrium position, which is about the same for all temperatures. Respiration also accounts for the loss of a small amount of sugar. One ton of husked, green, sweet corn during the first 24 hours of storage at 30°C. loses approximately 3.2 pounds of sugar on account of respiration.

These results show that temperature plays an important part in controlling the rate of sugar loss in sweet corn after harvest. Sugar being an important factor in determining eating quality, the temperature at which green sweet corn is kept after picking bears a close relation to edibility. According to Stevens and Higgins (1919), there is a generally accepted belief that sweet corn canned near the northern limit of its cultivation is sweeter and of better quality than that canned farther south. In a number of analyses made by Straughn and Church (1909), however, on the Stowell's Evergreen and Crosby varieties, there is no indication that sweet corn grown in the North has a higher sugar content at time of harvest. Tests were made over a period of 4 years and in a number of states from Maine to Florida. Stevens and Higgins (1919) believe that the superiority of the northern pack is due, at least in part, to the lower temperatures prevailing at time of harvest. Maine is the northern limit, and the latitude of Washington, District of Columbia, about the southern limit of the corn-canning industry. In the southern range, sweet corn is canned in August; while in Maine, it is usually canned during September. The temperatures prevailing in the southern range during sweet-corn-canning season are much higher than in the northern range. If the original quality and the methods of handling are the same, one would still expect a higher-quality product from the North because of temperature influences.

Varieties

Stowell's Evergreen.—This is the main variety grown for canning purposes. It is also much used for the late-market crop. The variety was originated by Mr. Stowell, a trucker of Philadelphia, introduced in 1861 by Thorburn under its present name, and, after more than 60 years, is still the standard late variety for all purposes. The stalks grow to a height of over 7 feet, the ears are about 8 inches long, and the kernels are large, deep, and white.

Oregon Evergreen.—In California, the Oregon Evergreen, probably a selection of Stowell's Evergreen, is very popular. It is smaller than the Stowell's Evergreen, somewhat earlier, and has become popular primarily because of certain husk characters which make it somewhat resist-

ant to the corn earworm. The husks are thick, fit tightly against the kernels, and extend 2 to 3 inches beyond the tip of the ear.

Golden Bantam.—A yellow-kerneled type similar to Golden Bantam has been in cultivation in the United States for perhaps 70 years. The stalks grow to a height of 3 or 4 feet. The ear is eight-rowed and about 4½ inches long. Golden Bantam is of excellent quality, matures early, and is a very popular market-garden variety. It is used to only a limited extent for canning.

Country Gentlemen.—The original broken-row variety of sweet corn was the Ne Plus Ultra, introduced by Johnson and Stokes about 1885. Shoe Peg, a narrow, deep-grained corn of the broken-row type was a selection made from the Ne Plus Ultra and was introduced by Johnson and Stokes, in 1890, as a distinct variety. In 1893, Peter Henderson introduced Country Gentleman. The latter is similar to Shoe Peg in almost every respect, except that the ear is considerably larger. Stalks attain a height of about 5 feet. The kernels are not in rows and are white, long, and narrow. Country Gentleman is a variety of excellent quality and is grown as a main- or late-season crop. It is much used for canning but does not yield as heavily as Stowell's Evergreen.

Crosby.—This variety is grown to a considerable extent for canning, especially in Maine and Minnesota. It is grown as a second early-market variety in the North. The plants are small; the ears are 5 to 7 inches long, with 12 or 14 rows of kernels. The kernels are short and white. Crosby yields somewhat less than does Country Gentleman.

Seed Selection

Size of Seed.—Hoffman (1925) compared large and small seed of the Country Gentleman variety of sweet corn. His results show that large kernels produce larger seedlings, which become established in the soil more quickly and grow more rapidly than those from small kernels. They reach the tasseling, pollen-shedding, full-silk, and canning stages about 5 days before plants from the small kernels do and are more even in maturity. A higher percentage of the stalks from large seed bears two ears, and there are fewer barren and unproductive stalks. While the stalks from large seed give the highest yield, the production per acre was highest in the plot planted with small kernels, because of the larger number of plants. The small kernels yielded 2.63 tons per acre; and the large kernels, 2.53 tons. There is no difference in the size of the kernels on the ears from large and small seed. Hoffman recommends grading the seed and planting the different sizes separately to obtain greater uniformity of ripening, which is especially desirable when the crop is to be canned.

Comparison of Performance of Seed from Different Parts of the Ear.—Comparative tests were made at the Nebraska Experiment Station by

Kiesselbach (1922) on seed taken from the tip, middle, and butt of the ear. There was almost no difference in yield of grain and in other plant characteristics from seed obtained in the different parts of the ear. Although the kernels at the tip of the ear are relatively small and their early seedling development is slightly backward, Kiesselbach (1922) states that they contain enough nutriment to support the seedling until it is able to synthesize its own food. He concludes that little is to be gained by discarding kernels from the butt and tip, aside from a somewhat more uniform dropping by the corn planter and a better germination under certain conditions of freezing injury.

Relation of Seed Maturity to Yield of Grain.—Kiesselbach (1922) selected corn at six different stages of maturity, as shown in Table 6. The data show that immature seed corn may possess both high germinative and yielding ability if well cured. The selection of immature seed is not recommended, however.

TABLE 6.—RELATION OF MATURITY OF SEED TO YIELD PER ACRE. HOAGUE'S YELLOW DENT CORN, 1916, 1917

(*Kiesselbach*, 1922)

Date of seed harvest	Condition of grain	Days since fertilization[1]	Weight of 100 kernels grams	Ratio weight of embryo to weight of kernel	Germination, per cent[2]	Yield per acre, bushels		
						1916	1917	Average
Sept. 1	Late milk stage	25	17.5	0.105	94	73.2	53.6	63.4
Sept. 8	Roasting ear	32	21.1	0.110	96	76.9	51.1	64.0
Sept. 15	Late roasting ear	39	24.8	0.103	97	73.2	52.8	63.0
Sept. 22	Denting	46	28.4	0.106	97	76.2	53.8	65.0
Sept. 29	Glazing	53	31.1	0.112	97	72.5	55.5	64.0
Oct. 6	Mature	60	31.6	.....	98	74.3	54.7	64.5

[1] Pollination occurred on July 31 and Aug. 10, 1916 and 1917, respectively.
[2] Data for 1917 only.

Kiesselbach states that

> . . . even though the viability and yield may not be impaired by immaturity, thorough field curing of seed should be practiced as far as possible, since difficulty of curing and preservation are thereby greatly reduced. The above test does not include the effect of unfavorable growth conditions in some seasons. It is possible that small, immaturely harvested seeds would be handicapped under unfavorable climatic or seed-bed conditions.

This conclusion is especially important in relation to sweet corn, because sweet corn is more difficult to cure than field corn.

BREEDING AND IMPROVEMENT

The object in sweet-corn breeding is usually to obtain strains or varieties of good quality which are high in production, ripen their ears uniformly, and are resistant to disease. The method of improvement

now recommended is that of inbreeding for several generations and then crossing certain of the inbred strains. According to Holbert, *et al.* (1925), self-fertilization can be likened to the analytical method employed by the chemist. The corn crop is resolved into its component elements, those useless are discarded, and the desirable ones are used to build up synthetically, by hybridization, the particular type desired.

By selfing corn for a number of generations, Kiesselbach (1922) isolated elemental strains differing

> . . . in such physical and physiological characters as height of stalk, diameter of stalk, leaf area, leaf width, erectness of leaves, suckering tendency, brace root development, lodge resistance, firing of leaves, firing of tassels, sterility of tassels, barrenness of ears, stalk and leaf color, grain color, cob color, silk color, anther color, tassel conformation, shank development, ear type, kernel type, grain yield, disease resistance and earliness of maturity.

As far as known, inbreeding of corn is always accompanied by a decrease in yield and vigor during the first few inbred generations. Jones and Mangelsdorf (1925) have reported on four strains of Leaming corn which have been self-fertilized for 17 generations. Their data show that there is a gradual decrease in yield and height of plant at first but that later, the plants within a strain are fairly uniform. These authors state that the vigor which is lost by inbreeding is at once restored when two self-fertilized lines descending from different plants at the start are crossed. A comparison of a large number of first-generation crosses between inbred strains derived from the same variety showed that the yield of hybrids was increased 180 per cent, height of plant 27 per cent, length of ear 29 per cent, number of nodes 6 per cent, and rows of kernels on the ear 5 per cent above the average of the inbred parents, which are of course relatively poor in yield and vigor. From this it is seen that size characters, such as height of plant and length of ear, are affected more noticeably by hybrid vigor than are the number of parts such as nodes and rows of grain on the ear, while yield, which sums up the entire growing capacity of the plant, is increased more than anything else. Cross-breds may average 10 to 20 per cent higher in yield than the best varieties. Another striking effect of crossing inbred strains is the hastening of time of flowering and maturing.

Richey and Mayer (1925) have shown

> . . . that there is little or no relation between the productiveness of the self-fertilized lines and that of their crosses and that the final value of the lines for crossing must be determined by comparisons of the productiveness of their crosses.

In order to get a reasonable amount of seed for planting, however, it is almost essential that the seed-producing parent in any cross be fairly productive, unless crosses are used.

The increased growth vigor is already apparent in the kernels of the crosses. Kiesselbach and Cook (1924) obtained a 11.8 per cent increase in weight of the kernels when eight combinations of selfed strains were used. In the strains of corn used, increase in weight of the kernels could only have been due to hybrid vigor, probably exerting itself in both increased endosperm and embryo growth.

According to Jones and Mangelsdorf, 1925:

> Hybrids produced by combining two fixed inbred strains are called single crosses and have the greatest uniformity and trueness to type of crossed corn. Where uniformity in size, shape and other ear characters and evenness in ripening are particularly important, as in sweet corn for market gardening and canning, it will probably be well worth while to use this method in spite of certain serious handicaps [chief of which] are the low yields and poor quality of the seed obtained from the weakened inbred plants, [which must be used to plant the commercial crop].
>
> The increased growth resulting from crossing is quickly lost in the following generations when the hybrid individuals are bred among themselves or again inbred. In other words, hybrid vigor is a temporary manifestation which ordinarily cannot be fixed and made permanent in sexually reproduced offspring.

These authors have obtained good results by again combining single crosses into double crosses. Inbred strains are combined first as single crosses, and the latter are then combined as double crosses. When this method is used, four pure, inbred lines will need to be carried along. One single cross must be used as the male parent and the other, as the female parent. The double crosses are not so uniform as the single crosses, because all of the plants do not have the same genetic constitution.

The production of cross-bred seed from inbred lines requires special technique and very close attention and may therefore be more successfully conducted by some seed specialist or central organization. The crosses do not maintain their high yields and other desirable qualities in later generations; so in order to secure the benefits of hybrid vigor, it is necessary to plant crossed seed each year. The cost of the seed may be doubled or even trebled, but it has been found that the returns will much more than pay for the increased cost of seed. In conducting a corn-improvement program, Jones and Mangelsdorf state that a variety should be selected which is adapted to the climate and purpose for which it is to be used. A number of the best ears are planted in separate rows of 20 or 30 plants each. Five of the best plants in each row are selected for self-pollination. A 3-pound parchment manila-paper bag is placed over each ear before the silks appear, and an 8- or 12-pound bag is placed over the tassel of the same plant a day or two later, before pollen begins to be shed. When the silks are out about 3 inches, the tassel bag with its enclosed tassel is inverted and then shaken to collect the pollen. Pol-

lination should be conducted only when the pollen and bags are dry. The ear bag is removed while pollen is being applied; care should be used to prevent cross-pollination. The ear bag may be replaced, and over it is placed the tassel bag. The bags remain on the ears until time of harvest. From the five self-fertilized ears in each line, the three best are selected for planting the next year. Each ear is again planted in a separate row. Two of the best plants in each row are self-pollinated. At harvest time, two ears are saved from the best and one from the second best progeny rows. The third, or poorest, progeny is discarded. By following this system, in three or four generations many of the lines are fairly homozygous. It is now necessary to make all possible combinations between the best-appearing strains, to find out which combinations give the best F_1 progenies. This preliminary crossing between different strains is best done by means of hand-pollination.

When the best combination has been determined by trial, it is then possible to produce the seed in quantity. The two inbred strains are planted in alternate rows in an isolated plot. The line that is to be used for the seed parent is detasseled before any of the pollen is shed. All the silks then receive pollen from the tassel-bearing strain. The crossed seed is used for field planting. Seed from the tassel-bearing rows can be used as stock seed for planting in the crossing plot the following year. By maintaining two crossing plots in separate fields, detasseling one type in one field and the other type in the second field, it is possible to have inbred stock seed of both types produced each year. In case one of the strains is superior as a seed parent, it can be propagated in an isolated plot to produce stock seed for planting in the crossing plot. Any outcrossed plants appearing in the inbred strain may be easily detected by their increase in size and change in type and should be rogued out. To obtain the maximum set of seed, pollen shedding should overlap the silking period. To secure this, it may be necessary to plant the pollen parent and seed parent at different dates or to make two plantings of alternate rows of the tassel-bearing strain at an interval of 10 to 14 days.

In a comparison of the histological features of pure lines with their hybrids, Kiesselbach (1922) found that in the case of the hybrids, (1) the diameter of the stalk is greater, (2) the vascular bundles are larger—there are more of them in the stalk but fewer per unit area, (3) there are more pith cells, and these are larger in size, (4) the leaf is thicker, (5) the upper and lower epidermal cells are larger, and (6) there is a considerable increase in leaf area. It is estimated that about 10.6 per cent of the total increase in size over the pure-line parents is due to cell size, while 89.4 per cent of it is a result of increase in cell numbers.

Selection Method.—According to Holbert, *et al.* (1924), for a considerable time careful seed selection will probably be the method used by the majority of seed producers and farmers in improving their corn. This

must necessarily be the case, because of the length of time required to obtain tested lines for use in producing hybrid seed. Much can be accomplished by paying particular attention to the plant in the field and to the ear in the seed house and in the germinator. Selection at these three stages plays a very important part in securing good seed for the next crop.

The parent plant should have an erect stalk, indicating a strong root system. It should be strong, vigorous, and healthy, free from smut, rust, and other diseases, with the leaves free from spottings, streakings, and purplings. The husks should be long enough to cover the tip of the ear completely. The angles which the ears form with the stalk should range from approximately 45 to 135°. Upright ears are likely to have large, coarse shanks, while ears hanging straight down are usually borne on small, weak, broken, or diseased shanks. A plant answering the above description is likely to be relatively free from infection by the corn-root organism and will ordinarily produce an ear which likewise is relatively disease free. Seed ears should be well matured, free from disease, and solid. The shank attachments should be free from discoloration due to exposure or disease.

Germinator Tests.—Germinator tests should also be made to detect those ears that have high viability and produce vigorous, disease-free seedlings. According to Holbert and Hoffer (1920), two methods of seed testing are now in use—the table germinator and the modified rag doll. The latter consists of a muslin cloth 12 by 54 inches long. This is boiled in water and placed on a strip of firm, water-finish-fiber paper of equal width and slightly longer. The kernels from each ear are placed in a row with the germ sides down and with the tips all pointing toward what will be the lower end of the rag doll when it is placed in the germinator box. The cloth is thoroughly wet, and then the paper, cloth, and kernels are carefully rolled up. Rubber bands are placed around each end of the roll. The upper end is labelled with a tag bearing the numbers of the ears used and the date of the test.

The rag-doll germinators are placed in a container which consists of an outer and an inner box, with sawdust between them. The inner box may be of any convenient size but should be at least 18 inches deep. Wire cross-rods are spaced about 3 inches apart in the upper part of the inner box to separate the rolls.

When in use, the sawdust is kept wet, the rag dolls are sprinkled twice daily, and the box is covered with wet cloths. The box should be kept at a temperature of 25 to 30°C. At the end of 7 days, the rag dolls are unrolled. Ears which are represented by rotted seedlings should be discarded. Some seedlings which appear healthy grow from kernels rotted on the inside. All kernels that seem sound externally should be cut open lengthwise. Ears should be discarded which do not give a high

percentage of germination and whose seedlings have weak and slender sprouts or short, slender roots.

Diseases

Corn Smut (*Ustilago zeae*).—The organism causing smut disease is found wherever corn is grown. The fungus causes rapid multiplication and enlargement of cells, resulting in hypertrophied growths on various parts of the plant. The spores remain viable in the soil for some time, and infection may occur throughout the season. According to Hitchcock and Norton (1896), the leaves are the first to be infected, then the tassels, ears, and lower nodal buds, because, in the development of the plant, they are successively exposed while still in a meristematic condition, which is the time of greatest susceptibility. According to Potter and Melchers (1925), moisture is not a limiting or controlling factor in the occurrence of corn smut, and infection depends more on the stage of development of the host plant than on the season. A common method of infection is the development of a virulent culture in moisture in the leaf axil of a young plant. Such a local culture is likely to produce other infections in adjoining nodal tissues and thus produce a pseudosystemic development of the disease.

Duggar (1909) states that when diseased, the mature cells of the host are very largely broken down, and the pockets of spores are surrounded by a membrane made up of modified fungous threads mingled together with dried host cells. This membrane is soon broken, and the loose spores are set free.

Control.—Probably the most promising method of control is the selection of strains that are resistant to smut. Jones and Mangelsdorf (1925), working in Connecticut, report that there is a marked difference between selfed strains in their resistance to smut. Potter and Melchers (1925) and other investigators have shown similar results. Removing and destroying the infected stalks or portions thereof before the spores have matured and also crop rotation should help control this disease.

Insects

Corn Earworm (*Chloridea obsoleta*).—The corn earworm is probably the most serious insect pest with which the grower of sweet corn has to contend. It is also known as the tomato fruitworm, tobacco budworm, and cotton bollworm.

The moth is about ¾ inch long. It may be dull olive green, yellowish, or nearly white. In the most typical moths, the wings are bordered with dark bands, the wing veins are black, and the fore wings are spotted with black. According to McColloch (1920), the adults are most active at night. During midsummer, they usually begin flying, feeding, and ovi-

positing at about 5:30 p.m. and may continue until dawn. On cloudy or cool days of fall eggs may be deposited during the day. One female may deposit from 500 to 2,000 eggs; as many as 570 eggs may be deposited in one night. The eggs are laid singly and usually one or two on a plant. In a study covering 6 years, it was found by McColloch that 32.7 per cent of the eggs were deposited on the upper-leaf surface, 9.4 per cent on the lower-leaf surface, 30.6 per cent on the silks, 2.6 per cent on the husks, 8.9 per cent on the tassels, and 15.8 per cent on the stalks. The silks are preferred, but the plant is in silk for a period of 4 to 8 days only, while the other parts of the plant are always available. The eggs are about $\frac{1}{15}$ inch in diameter, light yellowish, and of a finely ridged surface. Eggs hatch in 3 to 5 days, depending upon the temperature.

The larvae vary in color from green through rose and brown to almost black and may be either striped, spotted, or plain. Larvae are full grown in about $2\frac{1}{2}$ weeks; when mature, they are about $1\frac{1}{2}$ inches long. They enter the soil to pupate. The pupa is about $\frac{1}{5}$ inch long and shining, reddish brown. During the summer, the pupal stage lasts about 14 days, but in the fall the last brood pupates over winter. During midsummer, a little over a month is required to complete the life cycle. Fall and spring broods require somewhat longer than this.

Control.—The eggs, larvae, and pupae are killed by predaceous enemies, parasites, and unfavorable weather conditions. The larvae are cannibalistic, and when they meet they fight until one is killed. Often the vanquished is entirely consumed by its foe. Contact is very frequent in husks that are tight and extend for a considerable distance beyond the ear. In loose husks or uncovered tips, a number of larvae may enter and feed unmolested.

1. *Dusting Silks.*—Phillips and King (1925) recommend dusting the silks with a mixture of equal parts of powdered lead arsenate and finely ground S. The first application is given when the silks are 2 inches long and then repeated every 3 or 4 days until the silks are dry. This treatment is especially effective when the ears treated have long, tight husks, which compel the larvae to feed on the exposed silks before gaining entrance to the ear.

2. *Culture.*—Late fall and winter plowing exposes and destroys many of the pupae. It is possible to regulate planting, especially in the North, so that corn will not be in silk during the natural period of oviposition.

3. *Breeding for Resistance.*—According to McColloch (1922), the female moth, if depositing eggs on the corn leaf or stalk, prefers those plants that have a rough, hairy surface. Collins and Kempton (1917) found the least amount of injury on those ears that had the husks well extended beyond the tip of the ear. A thick covering of husks without husk leaves also reduces the amount of injury. Other things being equal, plants selected for resistance to the corn earworm should have a smooth

leaf, and the ears should have husks which are tight and extend well beyond the tip of the ear.

4. *Attractants.*—McColloch (1922) was able to attract the female moth and cause her to deposit eggs on imitation corn silks made of cotton twine or yarn soaked in corn-silk juice. This is an interesting line of attack, and it is possible that the use of attractants may in time develop into one of the major lines of control.

Rough-headed Corn-Stalk Beetle (*Euetheola rugiceps*).—The rough-headed corn-stalk beetle occurs mainly in the Southeast. According to Phillips and Fox (1924), the adult is rather stout and jet black; the recently emerged beetles have a highly polished surface, but in the old ones it is dull and opaque.

Corn is attacked by the adults when the plants are young. The plants may be attacked from the time they appear above ground until they are waist high. The beetles are especially fond of the apical growing point of the stalk. In older plants, when the terminal bud is well above ground level, the pith is the tissue usually attacked. The chief damage at this stage is the weakening of the stalk, which is then easily broken by strong winds. Later in the season the stalks are too hard for the beetles to penetrate.

Control.—A number of predaceous enemies and parasites help to keep this pest under control. Phillips and Fox (1924) suggest the following means of control: (1) crop rotation, including the pasture land in rotation, (2) intensive cultivation, (3) plowing the land when insects are pupating, (4) elimination of waste land, (5) good drainage, (6) pasturing the land with hogs during August and September to destroy larvae, (7) planting no corn on sod land if corn-stalk beetle is present, (8) hand picking when field first shows injury, (9) hastening growth by applications of commercial fertilizer.

Corn-root Aphis (*Anuraphis maidi-radicis*).—The corn-root aphis is probably distributed throughout most of the region east of the Rocky Mountains. It is reported by Vickery (1910) as particularly injurious to the corn crop in Maryland, Ohio, Indiana, and Illinois and as seriously damaging to the crop at times in eastern Pennsylvania, New Jersey, the Virginias, and the Carolinas. The aphis are bluish green in color, with a white, waxy bloom. The winged female has a black head and a brownish-black thorax, with pale-green abdomen. The eggs are oval and glossy black.

According to Vickery (1910), in Illinois, the eggs hatch in April and May, and from 10 to 22 generations may follow. Living young are produced throughout the summer. In late September or in October, sexual forms are produced; and eggs are laid in October and November, which hatch the following spring. The lives of the corn-root aphis and the cornfield ant may be considered interdependent. The ants collect the

eggs of the aphis in the fall and carry them to their nests, where they keep them during the winter. By bringing these eggs near the surface or carrying them deeper down into their burrows, the ants are able to control the hatching until weeds start to grow, upon which the young aphis can feed. As soon as the eggs hatch, the young are carried to the roots of young weeds such as pigeon grass, smartweed, and ragweed. The colonies of aphis are transferred to the roots of the corn when it begins to come up. Like all other species in this family, the root aphis secretes honey dew, upon which the ants feed. As this honey dew constitutes the principal food of the ants, the strength of each colony thus depends upon the number of aphis in its charge.

Control.—There are no natural checks to the multiplication of the corn-root aphis and its attendant ant, except hard rains, which may drown many of the aphis and also the young of the ants. Suggested means of control are: (1) crop rotation. Corn and cotton should not follow each other in the rotation; (2) maintenance of soil fertility; (3) deep plowing in late fall, winter, or early spring; (4) keeping fields free from weeds; (5) throughly mixing 3 ounces of a repellant made from lemon oil (1 part) and wood alcohol (9 parts) with each gallon of seed corn before planting.

European Corn Borer (*Pyrausta nubilalis*).—The European corn borer, while not widespread in the United States as yet, nevertheless constitutes a potential menace to the corn industry. At present, this pest is present in three separate areas in the United States: (1) eastern Massachusetts and southeastern New Hampshire (2) an area around Schenectady, New York, and (3) a short distance inland of all states bordering on Lake Erie. There is also an infestation in southern Ontario, bordering Lake Erie.

According to Coffey and Worthley (1922), the female moth is robust, varies from pale yellow to light brown in color, and has a wing expanse of a little over an inch. The male has a long, slender body, a slightly smaller expanse than the female, and is pale to dark brown, with sometimes a blue tinge. The egg is nearly flat and about $\frac{1}{25}$ inch in diameter, pale yellow becoming darker just before the larva hatches. Eggs are deposited in early evening and early morning in flat masses of usually 15 to 20 on the leaves and stem. The eggs overlap in the manner of shingles. The larva is at first about $\frac{1}{16}$ inch long, with a black head and pale yellow body. The larva molts five or six times, gradually becoming darker; and when mature, is about 1 inch long by $\frac{1}{8}$ inch thick. The pupa is shuttle shaped, light to dark brown, and from $\frac{1}{2}$ to $\frac{5}{8}$ inch long.

In the New England area, there are usually two complete generations each year. The mature larva hibernates within the tunnel made in its host, or shelter plant, during the previous summer and fall. About the middle of May it pupates, this stage lasting about 19 days. Soon after

emergence, the moths mate and begin to deposit eggs. The adults of both sexes live about 18 days. The eggs hatch in from 4 to 12 days, depending upon the temperature. The larvae of the summer brood mature in about 38 days. They pupate, and the adults emerge in about 11 days, during late July or early August. The eggs of this brood produce the larvae that survive the winter. The life history varies somewhat in the different areas.

All parts of the corn plant except the fibrous roots are tunneled. The most serious damage, however, is done by the larvae in the ears and stalks. Broken tassels with extrusions of frass at the breaks are the most conspicuous signs of infestation in fields of growing corn. Vegetables commonly attacked, other than corn, are beans, beets, celery, pepper, potato, rhubarb, and Swiss chard. Those occasionally attacked are artichoke, okra, parsnip, spinach, and tomato. Many thick-stemmed weeds and grasses also serve as hosts.

Control.—The following means of control have been suggested: (1) Burn or plow under by early spring all field refuse; (2) keep all fields and waste places free from large weeds and large-stemmed grasses; (3) remove corn fodder from the field as soon as mature, cut close to the ground, and shred or cut to increase its consumption. Sweet-corn fodder should be fed, placed in silo, or burned immediately after the ears have been removed; (4) plant small areas of early sweet corn as a trap crop adjacent to the fields intended for field corn or late sweet corn; feed or destroy this trap crop as soon as the ears are harvested or preferably just before; (5) do not plant corn within 50 feet of coarse-stemmed vegetables intended for sale; (6) comply with quarantine regulations.

Corn Wireworm.—The adult measures from ½ to ¾ inch in length. It varies in color from light, reddish brown to almost black and is commonly known as "click beetle." The beetles deposit their eggs in sod land. The larvae or "wireworms" are shining, reddish brown, from 1 to 1¼ inches in length, very hard, slender, and cylindrical. The corn wireworms in some cases live in the ground as long as 6 years.

Control.—(1) Good drainage, (2) thorough cultivation of waste land, and (3) fallowing will probably help to keep these insects under control. Satisfactory measures have not as yet been developed.

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PART II

LILIACEAE

The *Liliaceae* are widely distributed throughout temperate and subtropical countries. Many important food and ornamental plants are members of this family. The fragrant lily as well as the odoriferous garlic belong here. The species of greatest importance as vegetables are Asparagus officinalis, Allium cepa (onion), A. sativum (garlic), A. porrum (leek), A. fistulosum (Welsh onion), A. ascolonicum (shallot), and A. schoenoprasum (chive). Of these, asparagus and onions are by far the most important as garden crops.

CHAPTER II

ALLIUM

The genus *Allium* contains many species, some being native to North America. All members of this genus have the characteristic alliaceous odor; but in some species, the odor is much more pronounced than in others.

SECTION A. ONION

Onions are grown throughout most of the temperate regions of the world. Egypt, Spain, Italy, and the United States are the leading producers. The onion is one of the most widely grown vegetables in the United States and is produced as a home-garden, market-garden, and truck crop. Onions are shipped in carlots by 40 of the 48 states.

History.—The onion has probably been cultivated from remotest antiquity as an article of food. It is no longer found growing wild but is perhaps indigenous in the countries from Palestine to India. According to Sturtevant:

> It is mentioned in the Bible as one of the things for which the Israelites longed in the wilderness and complained about to Moses. Herodotus says, in his time there was an inscription on the Great Pyramid stating the sum expended for onions, radishes, and garlic, which had been consumed by the laborers during the progress of its erection, as 1,600 talents . . . Onions were prohibited to the Egyptian priests, who abstained from most kinds of pulse, but they were not excluded from the altars of the gods . . . They were introduced at private as well as public festivals and brought to table. The onions of Egypt were mild and of an excellent flavor and were eaten raw as well as cooked by persons of all classes.

It is not known when this crop was first introduced into America, but it was being cultivated in Massachusetts early in the seventeenth century. In 1883, Vilmorin described 60, and in 1923 Morse described 77 distinct varieties.

Plant Characteristics

Roots.—The root system of the onion is fibrous. Roots continue to arise from the stem plate during the entire time the plant is growing. According to Goff (1886), a young onion plant with leaves 8 inches long was found to have roots extending to a depth of 16 inches; most of the roots of full-grown plants extended no deeper. A few roots reached a

depth of 18 inches. The roots radiated from the stem plate in all directions from horizontal to vertical. Some horizontal roots were not more than an inch beneath the surface and extended about one foot. A mature bulb planted in the spring developed the same type of root system. Forty days after planting, the root system was estimated at 400 linear feet.

Thompson (1920) found very few roots that reached a depth of more than 10 inches, although some went as deep as 20 inches, while the lateral spread of roots was 6 to 12 inches, and the main root zone was found within a radius of 6 inches of the stem. The type of development probably varies under different soil conditions, but it is evident that the feeding range of the onion is limited.

Leaf and Stem.—The leaves of the onion arise from a very short, conical stem, or "stem plate," at the base of the bulb. The outer leaves are the oldest, and their sheaths completely surround those within. The leaf-bases thicken and become the "scales" of the onion bulb. The leaf-blades are cylindrical and hollow.

Inflorescence.—The flowers are borne in simple umbels at the terminal end of an elongated stalk, which, although it may develop to a height of 5 or 6 feet, reaches usually but to 3 or 4. The number of seed stems per plant varies from 1 to 20 or more. Large mother bulbs produce more seed stems than small ones. There is also a difference between varieties. Under California conditions, Yellow Danvers Flat produces a greater number of seed stems than most other varieties. The umbel is enclosed within two or three papery bracts until shortly before the first flowers begin to open. The bracts are split open by the pressure of the developing flower buds within. The pedicels may vary from short and rigid to long, slender, and very flexible. The number of flowers in an umbel may vary from 50 or less to 2,000 or more. The buds of an umbel vary considerably in age, and they do not appear in any definite order.

When the bulbs are planted in late autumn or early winter, the floral axis does not begin to develop until late winter or early spring. In Maryland, the developing floral axes were first observed by Jones and Boswell (1922) in late March. At Davis, California developing floral axes were first observed late in February.

Flower.—The flower has an outer and inner whorl of stamens with three members in each. The pistil has a three-celled ovary with two ovules in each locule. The anthers of the three inner stamens are the first to dehisc, shedding their pollen one after the other at irregular intervals. After this, the anthers of the outer whorl of stamens dehisc. All the pollen of the flower is shed within a period of 24 to 36 hours, before the stigma becomes receptive. The style is approximately 1 millimeter long when the flower first opens; it does not reach its maximum length of about 5 millimeters until some time after all pollen has been shed. The

flowers of an inflorescence may continue to open over a period of 2 weeks or longer. A plant may be in flower for 30 days or more.

Pollination.—Most of the pollen is shed between 9 a.m. and 5 p.m. Wind and gravity play only a small part in pollination under natural conditions. Various species of insects go from flower to flower and visit

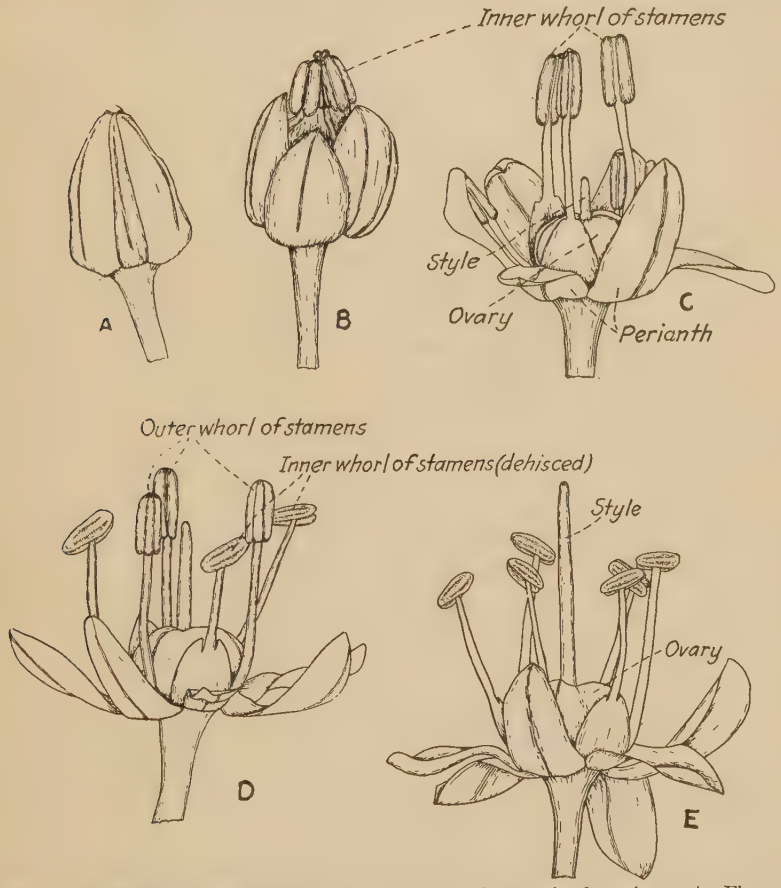

FIG. 6.—Method of flower opening and anther dehiscence in the onion. A. Flower bud just before anthesis. B. Perianth expanding and inner whorl of stamens elongating. C. Just before dehiscence of inner whorl of stamens. Note the short style. D. Inner whorl of stamens has dehisced and the outer whorl has elongated. E. Both whorls of stamens have dehisced. Note the long style which is now receptive.

the nectaries in the axils of the three inner stamens. Inter-pollination among flowers of the same umbel is probably of very frequent occurrence, as the same insect may visit a large number of flowers before leaving. Since the onion flower is chiefly insect-pollinated, crossing is also common, and it is essential that different varieties, when grown for seed, be planted at least ½ mile apart.

Fruit and Seed.—The fruit of the onion is a capsule. The greater part of the seed is endosperm. The cell walls of the endosperm are very much thickened and may be composed of from five to nine lamellae perforated by pore canals. The reserve food in the wall layers is probably hemi-cellulose, while that in the lumina of the endosperm cells is chiefly fat and protein. The spirally twisted, cylindrical, thread-like embryo is embedded in the endosperm. The greater part of the embryo is cotyledon. Within the cavity of the cotyledon is the slightly developed primordium of the first leaf.

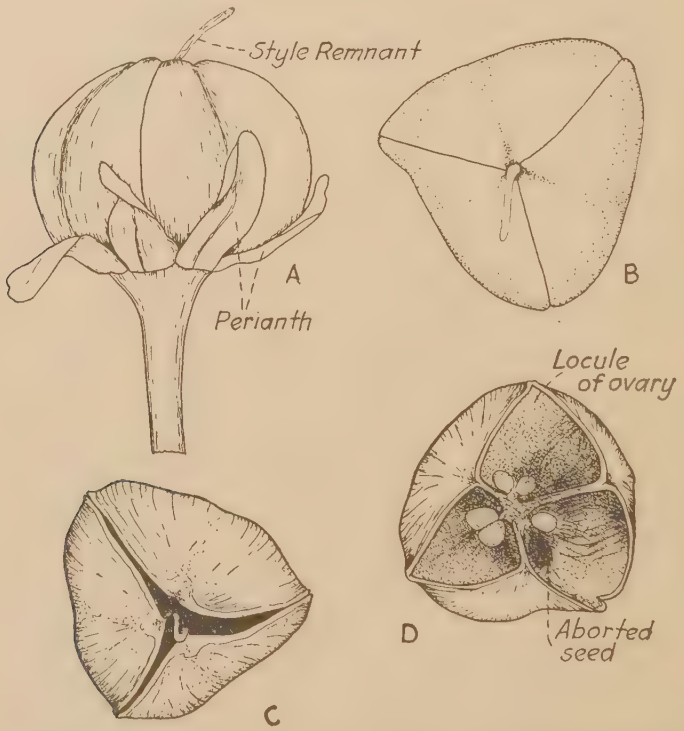

FIG. 7.—A, B. Side and top view of almost mature ovary. C. Dehisced capsule with seed. D. Dehisced capsule with seed shed.

CLIMATIC AND SOIL REQUIREMENTS

Onions are grown mainly on sandy loams, silty loams, and muck. A large proportion of the onions in the North and in California are grown on muck soils, which are usually loose, have a high water-holding capacity, and are, as a rule, very fertile. The onion plant is not very tolerant of acid soils. Shutt and Smith (1918) report a good growth of onions on soil containing 0.135 per cent sodium carbonate, a fact which indicates that the crop is somewhat tolerant of "black alkali."

In a study of the influence of crop plants on those that follow, Hartwell and Damon (1918) obtained 13 bushels of large onions per acre after beets and cabbage, 14 after rutabagas, 17 after buckwheat, 35 after potatoes, 87 after spring rye, 131 after corn, 143 after millet, 161 after onions, 175 after oats, 178 after red clover, 293 after timothy, 314 after alsike clover, 406 after timothy and redtop, and 412 after redtop. Before planting to onions, the above plots grew the crops listed for 2 years; and for the 8 years preceding this, they were all given uniform treatment. Onions seem to grow well following grasses, cereals, and clovers. It was found that application of lime overcomes the deleterious effect of buckwheat on the next crop of onions.

During early growth, the plant requires available soil moisture near the surface. New roots are not formed unless the zone from which they arise is in moist earth. The plants must be kept growing; if growth is checked temporarily, due to shortage of water, the outer scales seem to mature; and when water is again added, the inner scales resume growth, splitting the outer ones. This is one of the main causes of splits and doubles where onions are grown under irrigated conditions.

For their best development, onions require cool weather during the early part of their growing period and a dry atmosphere and moderately high temperature during the latter part. The young plants withstand temperatures several degrees below freezing. Walker and Jones (1921) find that the best root development occurs at soil temperatures ranging from 12 to 20°C., while the most rapid growth of tops, at least during the early-growth period, is obtained at 20 to 25°C. In 30-day tests of Red Globe and Yellow Bermuda, the former was found to have a distinctly lower temperature requirement. Not only is there a different optimum for the root and top growth of the individual plant, but this optimum varies between varieties.

Long light-duration is necessary for bulb development. Garner and Allard (1923) state that plants of the Silverskin variety continued growing but formed no bulbs when exposed to 10 hours of light each day. Bulbs formed when plants of this variety were exposed to 13 hours of light daily out of doors or to the full day of summer. Onions planted in early fall may grow a luxuriant foliage during late fall and winter, but bulbs are not formed until spring.

Culture

Seeding.—Most of the onions grown for late market or storage are seeded directly in the field. The soil must be in a finely pulverized condition and free from debris. Seed is usually sown at the rate of 3½ to 4 pounds per acre and at a depth of ½ to 1 inch, depending upon the soil type. Various types of garden seeders are used; these are run singly or in gangs. Rows are spaced from 8 to 18 inches apart.

Germination.—Onion seed germinates at temperatures ranging from 8 to 30°C. Kotowski (1926) planted onion seed of the Yellow Globe Danvers variety 2 centimeters deep in quartz sand at temperatures ranging from 4 to 30°C. As shown in Table 7 good germination was obtained at all temperatures except 4°C. The highest percentage of germination, however, was obtained at 18°C.

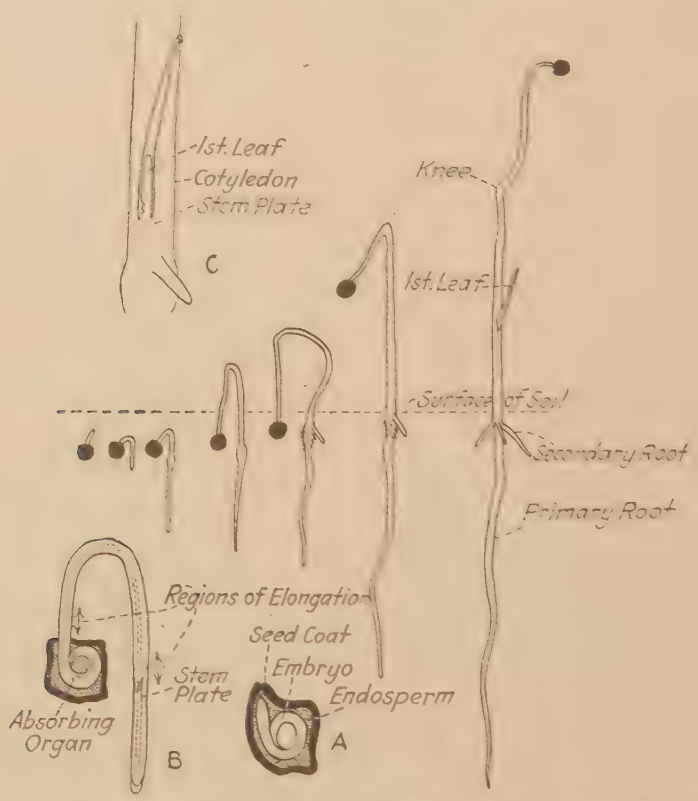

FIG. 8.—A to D. Germination and growth of onion seedling. (*Redrawn from Anderson* 1921.)

TABLE 7.—GERMINATION OF ONION SEED AT DIFFERENT TEMPERATURES

(*Kotowski*, 1926)

Temperature, °C	4	8	11	18	25	30
First seedling, days after sowing	0	30	17	8	6	5
Last seedling, days after sowing	0	43	29	18	17	13
Seedlings in per cent of seed sown	0	82	86	98	91	91

According to Sachs (1863), the growth of the embryo in germination begins with the elongation of the lower and middle portion of the cotyledon. This forces the root and stem through the seed coat. When that portion of the embryo outside of the seed coat is 4 to 6 millimeters long, it starts to bend downward, curvature taking place in the elongating portion of the cotyledon just above the stem plate. In time, the radicle points downward, and the place of bending becomes a sharp-pointed knee. There are two regions of growth in the cotyledon, one near the seed and the other just above the stem plate (Fig. 8). There are two stationary points above which the cotyledon elongates; the spiral-shaped absorbing organ is held stationary within the seed, while the root holds the opposite end of the cotyledon. For a time, both halves of the curve grow in length at the same rate, and, as a result, the knee soon appears through the soil. The absorbing organ remains within the seed coats, and the reserve food is digested and translocated to the growing regions of the embryo. When the seed is not covered sufficiently deep, or when the soil is not firmed, the seed may be pulled out of the soil before the endosperm has been entirely absorbed. The dissolving of the cellulose layers proceeds gradually from the lumen to the middle lamella. When exposed to the atmosphere, the seed dries out, and the digestion and transference of food is stopped.

The primary root usually reaches its full development about the time the absorbing organ is freed from within the seed coat. If the primary root has become established and the soil adjacent to the plant is too dry for the secondary roots to start, the primary root may function for several months. It is known to have functioned without additional help until a bulb several centimeters in diameter was formed.

Planting Date. In California and in other regions of mild climate, seeding is done during the winter. If sown too early, there is danger that a high percentage of the plants of certain varieties will form seed stalks. In the North, seed is sown as soon as the ground can be worked in the spring. Lloyd (1914), in Illinois, made plantings at different dates for 6 years. The first planting was made each spring as soon as a good seed bed could be prepared. Subsequent plantings were made at intervals of about 14 days. The onions from the earliest planting usually grew almost as late as those from the second planting and sometimes fully as late. The growing period averaged 13 days longer for the earliest planting than for the second and 11 days longer for the second than for the third. In general, the period of growth, the size of bulb, and the yield decreased as the date of planting was deferred. Table 8 gives an average of the results obtained over the 6-year period. The late planting was made only 4 out of the 6 years.

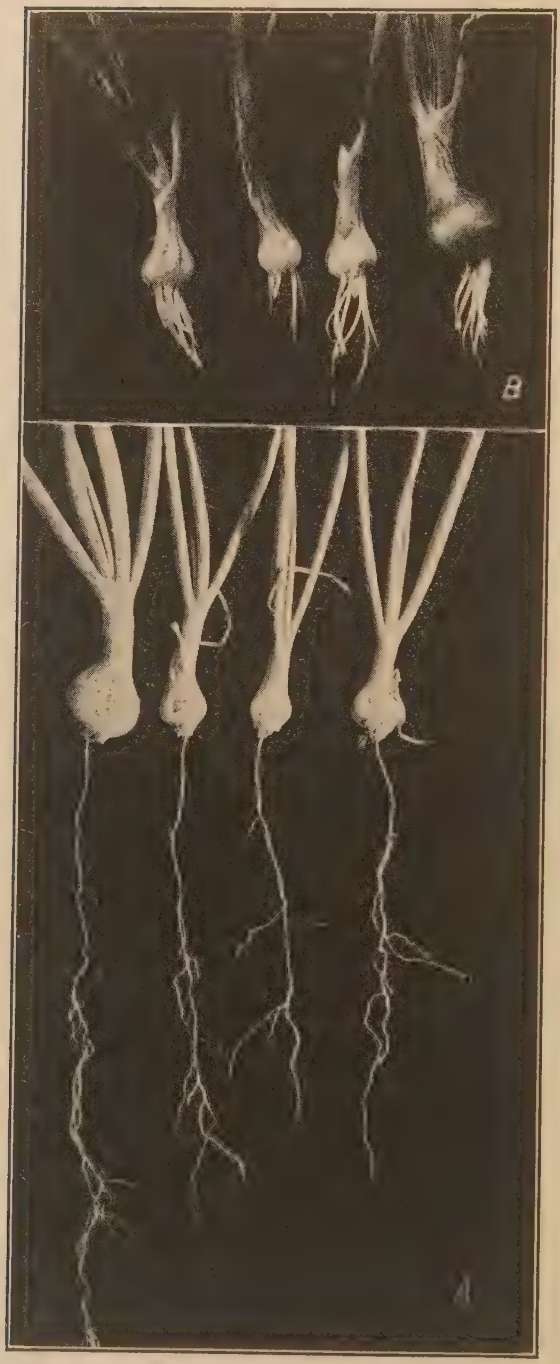

FIG. 9.—A. Primary roots only functioning due to growing in dry soil. B. The same plants 48 hours after water has been applied, showing the development of the secondary roots.

TABLE 8.--INFLUENCE OF PLANTING DATE ON DAYS TO MATURITY, YIELD AND VALUE OF CROP
(*Lloyd*, 1914)

Planting time	Average number of days from seeding to maturity	Average yield in bushels per acre			Average weight large bulbs, pounds	Value of onions per acre, dollars
		Large	Small	Total		
First planting.....	137	323.82	21.92	345.74	0.177	243.92
Second planting.....	124	295.93	21.82	317.75	0.157	219.95
Third planting.....	113	198.21	21.12	219.93	0.140	153.41
Fourth planting.....	110	174.29	44.29	218.78	0.136	153.69

The best returns were obtained from the first two plantings, because of the large yields and the low percentage of small bulbs.

Cultivation and Weeding.—A light hand harrowing is sometimes given in order to break the crust over the row and destroy weeds before the plants are through the ground. Cultivation is usually done by man power, but garden tractors which cultivate several rows simultaneously are now being used. Considerable hand weeding in the row is necessary; and under average conditions, this is the most expensive operation.

Thinning.—Thinning is now practiced to a lesser extent than formerly, because of the expense. An effort is made to regulate the stand at time of seeding. In muck and peat soils there is little danger of obtaining deformed bulbs from crowding.

Growth of the Plant.—Leaves originate at the growing point of the stem. They arise alternately at the nodes and are two-ranked. The growing region is near the base of the sheath. The young leaves make their exit through an opening in the surrounding sheath. For a time, the diameter of the sheath region is uniform. When the outer-leaf bases start to thicken, the new leaves that arise do not develop a leaf blade. In the normally matured bulb, about one-half of the weight consists of the inner-leaf sheaths with aborted blades. If the bulb ripens properly, each inner leaf should be completely enclosed within the one surrounding it. If the blades of the inner leaves continue to develop, thick-necks, or "scallions," are formed; these fail to ripen properly and do not keep well in storage. If care is used in seed selection, the development of scallions can be nearly eliminated, even under adverse growing and ripening conditions.

Ripening.—When plants ripen properly, the leaves weaken in the region just above the bulb, and the top falls over while the leaves are still green. If the tops dry from the tips toward the base while standing erect, the neck is not closed, and the bulbs do not keep well in storage.

Harvesting.—According to Cance, *et al.* (1916), the proper time to pull onions is determined to a certain extent by whether the onions are to be stored or placed on the market immediately. If they are to be marketed immediately, they should be fairly well ripened; but if they are to be stored, they should be pulled rather green and allowed to cure in storage. If onions are ripe when pulled, they have a tendency to take root easily. Onions pulled slightly immature seem to retain their outer skins better and are less likely to sprout and root when curing but are not as solid as when pulled fully mature.

Onions are usually pulled by hand and thrown in windrows to dry. Where the sun is especially hot, the tops are laid in such a manner as to protect the bulbs, especially in the case of the white varieties. They are left lying in the windrows for several days. When dry, the bulbs are topped by hand or by use of power-driven machines, which grade and deliver the bulbs into crates or bags.

Growing Onions from Dry Sets

Small, dry onion bulbs, called "sets," are used for the production of an early crop, which usually matures from 3 to 4 weeks earlier than a crop grown from seeds. Sets are now planted very largely by machine, which reduces considerably the cost of growing. According to Erwin and Harter (1925), the onion growers of Pleasant Valley, Iowa, were the first to plant with machines. With these, one man can plant an acre a day. The planters drop the sets tops up and space them evenly, if the bulbs have been carefully sized over a screen. The sets used in Pleasant Valley, Iowa, are graded into two sizes; of the larger size it requires about 25 to 30 bushels to plant an acre; and of the smaller size, 20 to 22 bushels. Lloyd (1914) compared the yield of Yellow Globe when grown from seed and from sets. The yield from seed was 346 bushels and from sets, 459 bushels per acre. The onions from seed matured in 137 days; and those from sets, in 112. The cost of production per acre from seed was $102 and from sets, $155. The profits from the latter, however, were greater because of the larger yields, earlier maturity, and larger size of the bulbs.

The Ebenezer, Yellow Danvers Flat, Yellow Strasburg, White Portugal, and Red Wethersfield are all grown to some extent from sets; the yellow varieties, however, are produced in largest amount.

When dry-onion sets are used for the production of green bunch onions, they are planted close together, and the plants are pulled, as a rule, about the time they start to bulb. Sets should be planted deep for green bunch onions to obtain a long, well-branched, edible portion. For green onions, white sets are preferred.

Production of Dry-onion Sets

Onion sets are small bulbs produced by growing the plants under crowded conditions in the field. They are grown to some extent in most of the northern onion-producing states, especially near Chicago, Ill. On productive soil, from 80 to 100 pounds of seed are sown to the acre; while on poorer soils, from 60 to 80 pounds are used. Seed must be sown thickly to prevent the sets from becoming large. If over ½ inch in diameter, it will form seed stalks the following spring, which is undesirable in the production of bulbs for market. The tendency to form seed stalks varies considerably among varieties, among strains of the same variety, and under different environmental conditions. For the production of sets, the flat varieties are used almost exclusively, because they make globe-shaped sets and keep well in storage. Globe varieties make elongated sets; they usually mature with a somewhat open neck and therefore do not keep well. The flat varieties also mature somewhat earlier than the globes, a fact which is important when they are grown for the early market.

When mature, the sets are loosened by running a U-shaped knife below the row. They are then gathered and placed in shallow trays with lath bottoms. The crates of onions are left scattered for a day or two to dry, then stacked in the field until stored.

Growing Onions from Green Sets, or Seedlings

Most of the Bermuda varieties and many of the large Spanish and Italian onions are grown from transplanted seedlings, or "green sets." The production of Bermuda onions is confined largely to southern Texas and to the Coachella Valley of California. The seed is sown in late summer or early fall in open beds, and the seedlings are transplanted in late fall or early winter. When pulled from the seed bed, the roots of the seedlings are trimmed to a length of about 1 to 1½ inches. The tops are also trimmed back to within an inch or two of the sheath.

Harvesting is usually done before the tops are dry. The bulbs are pulled by hand and stacked in piles, so that the tops protect them from the sun. The bulbs are topped, cured for a day or two, then graded by hand and packed in crates in the field for shipment.

In the North, seed of the Prizetaker and similar varieties is often sown in hotbeds or cold frames during the winter and transplanted to the field in early spring. This gives a long growing season, and the plants make considerable growth before hot weather. Field-grown plants from the South are also shipped extensively to the North. Where the winters are mild, varieties like the California Early Red and the Italian Red are planted in seed beds in August or September and transplanted to the field in late fall or early winter.

Marketing

The quantity of onions consumed per capita in the United States is fairly constant. Most fruits and vegetables are purchased more liberally when they are cheap, but this is not true to any appreciable extent with the onion. Though not used in large quantities in the average home, small amounts are required throughout the year. Hence, the onion market is inelastic, oversupplies being not readily absorbed.

Grading.—The bulbs are graded by passing over slatted tables. The slats are far enough apart to allow the debris and the onions less than 1½ inches in diameter to pass between them. In general, U. S. Grade No. 1 onions must be of similar varietal characteristics—firm, mature, well-shaped, free from doubles, splits, bottle necks, scallions, dirt, tops, or other foreign matter and from damage caused by sprouting, freezing, disease, insects, or mechanical or other means. A tolerance of 5 per cent is allowed below the requirements of this grade, but not over two-fifth of this tolerance is allowed for decay. U. S. Grade No. 2 consists of onions which do not meet the requirements of U. S. Grade No. 1. These grades may be classified according to size, as follows: boilers, ¾ to 1½ inches in diameter; small, 1½ to 1¾ inches; medium, 1¾ to 2¼ inches; large, over 2¼ inches; very large, over 3 inches. This last grade applies especially to the large Spanish onions. Not more than 5 per cent, by weight, may be below the specified minimum size, and not more than 10 per cent, by weight, may be larger than the specified maximum size.

Containers.—Most of the northern-grown onions are marketed in 100-pound sacks. The so-called "grass sacks" are the most popular. They have a coarse mesh through which the bulbs can be seen readily, are attractive, give good ventilation, and facilitate inspection by the prospective buyer. Bermuda onions are generally marketed in slatted crates.

Shipping.—Onions are shipped every month of the year. Bermuda onions are shipped directly from the field; most of them move from April to June. Onions from dry sets are shipped during July, and in August the main crop starts to move. The latter supplies the market, either from field or storage, until March. The winter shipments are mostly from storage. In Table 9 are given the carlot shipments by months for the entire United States. The greatest carlot movement is during September and October; at this time, the crop of onions in the North is removed from the field. While most of the crop is stored locally, some storing is done at terminal markets, a fact which accounts for most of the increase in carlot movements during these 2 months. Fewest cars are shipped during June, after the bulk of the Bermuda crop has been moved and before the spring planted crop is ready. Table 10 gives the shipping seasons and carlot movements for the important onion states.

TABLE 9.—CARLOT SHIPMENTS BY MONTHS FOR ENTIRE UNITED STATES, 1920–1926

Year	January	February	March	April	May	June	July	August	September	October	November	December
1920	1,368	1,159	999	1,938	4,242	607	1,030	1,918	3,675	4,910	2,918	1,186
1921	2,038	1,769	1,724	2,511	2,559	822	1,482	2,048	3,361	2,608	1,248	1,148
1922	1,724	1,011	719	3,085	2,301	937	1,695	2,497	4,603	5,129	2,185	1,677
1923	2,110	1,484	1,569	1,370	2,541	762	1,502	2,243	3,865	4,940	2,676	1,685
1924	2,573	2,225	1,998	2,371	2,895	985	2,192	2,511	4,055	4,918	3,152	2,047
1925	2,926	2,094	1,614	2,936	1,991	649	1,856	2,468	4,147	5,171	2,968	1,554
1926	2,642	2,328	1,860	1,916	4,006	1,258	1,732	2,488	3,726	5,426	2,852	2,491

TABLE 10.—SHIPPING SEASONS AND CARLOT MOVEMENTS OF MORE IMPORTANT ONION STATES

State	Approximate shipping seasons	Carlot shipments				
		1922	1923	1924	1925	1926[a]
California	All year	3,555	3,800	3,251	3,313	3,345
Colorado	September to March	392	857	1,166	1,323	1,898
Idaho	September to March	111	247	361	751	608
Illinois	August to March	467	379	248	265	205
Indiana	August to April	4,332	4,188	3,764	3,943	4,159
Iowa	July to March	898	881	1,180	1,316	1,428
Kentucky	June to July	255	264	268	150	135
Louisiana	May to June	91	81	24	272	171
Massachusetts	July to April	1,735	2,158	2,731	2,868	3,432
Michigan	September to April	1,643	1,068	1,708	1,385	1,896
Minnesota	September to April	444	205	433	600	695
New Jersey	June to December	479	321	415	235	253
New York	July to May	2,353	4,771	5,602	5,236	4,050
Ohio	August to April	4,124	2,523	4,173	2,768	1,856
Oregon	September to April	197	348	523	516	657
Pennsylvania	July to April	106	92	72	54	64
Texas	March to August	4,630	3,027	3,918	3,940	5,328
Utah	September to December	146	194	221	563	600
Virginia	June to August	371	274	345	138	168
Washington	July to April	853	1,109	1,042	939	1,251
Wisconsin	September to April	271	244	223	337	209
Total for United States		27,562	27,189	31,922	31,072	32,725

[a] Subject to revision.

In seasons of low production, considerable quantities of onions are imported. They are usually imported in largest amounts from the Gandia, Denia, and Valencia sections of Spain. The Valencia and Denia,

which are large varieties similar to Sweet Spanish, are shipped. The shipping season is mainly from August to November. Egypt, Bermuda, the Canary Islands, Canada, Italy, and other countries ship considerable quantities to the United States when prices are favorable.

Storage.—Onions are stored in bulk or in sacks or crates. In most sections, 2-bushel crates are preferred, especially if the onions are to be stored for some time. Onions keeps best in storage at about 32°F. and in a dry atmosphere. Shrinkage in storage from sprouting, rotting, and other causes usually ranges from about 7 to 15 per cent. Shrinkage may be as high as 50 per cent or higher if the bulbs are stored for a long time under warm, moist conditions or if the particular variety, or strain, has a short rest period.

The duration of the natural rest period of different varieties varies widely. As a rule, those varieties and strains which have thick outer scales, cure well at the neck, and are hard and firm have a longer rest period than those which have thin outer scales, are open at the neck, or are soft. Varieties such as the Australian Brown and Ebenezer do not start growth for several months, even when placed under conditions favorable for growth. The meristematic stem tip and young leaves are tightly enclosed by the surrounding scales, and it has been suggested (Jones, 1920) that the latter may act as membranes, retarding the intake of oxygen and thereby inhibiting growth. In time, however, they become more permeable and permit the entrance of sufficient oxygen to start growth. Boswell (1923) states that when upper portions of the bulbs are removed by transverse wounding, there is a stimulation of leaf growth and that the closer the cut is made to the growing stem tip, the more promptly does growth start. The breaking of the rest period by removal of portions of the bulb seems to be associated with an increased supply of oxygen rather than with wound stimulus.

Classification and Varieties

Bailey (1887) divides onion varieties into three groups, according to their method of propagation:

Propagated by division: Potato onions. Multipliers

Propagated by bulblets or top sets: Egyptian or winter onions

Propagated by seeds: Yellow Globe Danvers, Ebenezer, Prizetaker, Red Bermuda, and other common varieties.

Morse (1923) lists the following as leading American varieties: (1) Australian Brown, (2) Extra Early Red Flat, (3) Ohio Yellow Globe, (4) Prizetaker, (5) Red Wethersfield, (6) Southport Red Globe, (7) Southport White Globe, (8) Southport Yellow Globe, (9) White Portugal, (10) Yellow Danvers, (11) Yellow Globe Danvers, and (12) Yellow Strasburg.

The Bermudas are also very important, and so are the Spanish varieties. Almost the entire Texas crop and that of the Coachella Valley of California are Bermudas. The Spanish varieties, such as Sweet Spanish, Denia, and Valencia are becoming very popular. Ebenezer, too, is increasing in popularity.

Australian Brown.—Introduced into America by C. C. Morse and Company in about 1894, this is an important variety in the delta region of California. It is also grown to some extent in Oregon and Washington. The outer dry scales are various shades of brown and are very thick. The flesh of the bulb may be a pure, lemon yellow or slightly tinted with red. It is an excellent keeper, medium sized and slightly flattened. It seems to be especially susceptible to pink-root, but this may be due mainly to its late maturing habit. The variety is a heavy seeder.

Ohio Yellow Globe.—This variety is grown to some extent in all the northern onion-growing regions. The outer scales are dark yellow and thickened; it is a good keeper. It grows to about the same size as Southport Yellow Globe. It is slightly darker in color than Southport Yellow Globe, more nearly the color of Yellow Globe Danvers. In shape, it is a slightly elongated globe with a flat bottom. It matures about the same time or slightly later than the Southport Yellow Globe.

Prizetaker.—Prizetaker is grown to some extent by market gardeners for local consumption throughout the entire country. The transplanting method is usually used, and heavy yields of large bulbs are produced. The outer dry scales are straw color and medium heavy. Prizetaker is a poor keeper. In shape it is a perfect globe. The foliage is light green and seems to be somewhat more resistant to mildew than the Yellow Globe Danvers and similar varieties. Denia, Valencia, and Sweet Spanish do not differ materially from Prizetaker. Some strains of the former three, however, are excellent keepers.

Red Wethersfield.—This variety originated in Connecticut before 1863 and is named after the town of Wethersfield. The outer scales are a purplish red, darker than Extra Early Red Flat, but the color is not as intense as that of the Southport Red Globe. The flesh is tinged with red. It is a fairly good storage variety, though somewhat inferior to the Yellow Globe Danvers. It matures somewhat earlier than most of the globe-shaped varieties. The bulb is flat and is a goodseeder. Like other flat varieties, Red Wethersfield is grown to some extent for sets.

Southport Yellow Globe.—This variety originated in Connecticut, apparently near the town of Southport, as did also the other Southport varieties. The outer-scale color is yellow, not as deep, however, as in Yellow Globe Danvers. It usually matures slightly earlier than the Ohio Yellow Globe and is an excellent keeper. It is a perefct globe in shape,

but many seedsmen select the elongated type, provided that the neck is small and well matured.

Southport White Globe.—The outer-scale color is a pearly white, and the flesh is white. Southport White Globe matures at about the same time and is about the same size and shape as the other Southport varieties. In shape it is a perfect globe, but most seedsmen select a high bulb if the neck is well ripened. It does not keep so well as the other Southport varieties.

Southport Red Globe.—The outer-scale color is a dark, purplish red, even darker than Red Wethersfield. Its flesh is tinged with red. It matures at about the same time as Southport White Globe and keeps better. Most seedsmen select the oblong-globe shape.

White Portugal (Silverskin).—This variety is grown for white-onion sets and as an early-market white onion. The outer scales are pearly white. Some strains of the variety keep very well in storage, but, as a rule, White Portugals do not store so well as the Yellow varieties. In many strains, there is a tendency to form doubles, but this can be eliminated by selection. The bulb is large, flat, and similar in shape to Yellow Danvers Flat. It is very susceptible to smudge disease.

Yellow Danvers (Yellow Danvers Flat, Round Yellow Danvers).—This variety is grown to some extent for an early-maturing yellow onion. It is grown from both seed and sets. The outer scales are yellow, about the same shade of yellow as Yellow Globe Danvers. The flesh is very hard, and the onion is an excellent keeper. It is medium large, somewhat thicker in relation to its diameter than Yellow Strasburg, keeps well in storage, and is a very good seeder.

Yellow Globe Danvers.—The Yellow Globe Danvers originated in Massachusetts, near Boston, before 1850 and is probably the most widely grown storage onion in America. The outer scales are dark yellow. It matures earlier than the Southport Yellow Globe, is somewhat smaller than the latter, and is a perfect globe in shape.

Yellow Strasburg (Yellow Dutch, Strasburg).—This variety is used mainly in those regions where mature onions are grown from dry sets. It has declined somewhat in popularity during the last few years, and its place has been taken to a certain extent by the Ebenezer. The outer scales are light yellow or straw colored, and the neck is almost white when dry. The mature bulb is hard and an excellent keeper It matures at about the same time as Yellow Globe Danvers and does not grow to a very large size, nor is it as thick in relation to its diameter as is the Yellow Danvers Flat.

Breeding

The object in onion breeding is to obtain strains that are uniform in color, shape, size, and time of ripening and high yielders, good keepers,

good resisters of disease, and heavy seeders. The best method of getting these results is inbreeding and selection within inbred lines. In the breeding work at the California Experiment Station, desirable bulbs are selected from commercial varities and planted in the field. When the first flower opens, the entire inflorescence is enclosed within a 1-pound manila-paper bag. All necessary field data are written on the bag at the time of bagging. The bag is tied securely about the seed stalk below the umbel. Each day, about noon, and again, toward evening, the bags are tapped to facilitate pollination. When the seeds are ripe, the seed stem

FIG. 10.—Method of bagging flower heads to obtain selfed seed. University Farm, Davis, California.

is cut below the bag. When dry, the contents of the bag are emptied into a small cloth sack and threshed by rubbing between the hands. When placed in water, the heavy seeds sink and the light seeds and chaff float. About 30 different varieties have been handled in this way, and from most plants sufficient seed is obtained to carry on the strains. Only occasionally do strains appear that are entirely self-sterile. In 1923, 33 plants of Yellow Danvers Flat were selfed, and the number of seeds obtained per plant ranged from 26 to 2,812. In the second generation of these lines, no complete sterility appeared. The bulbs of the first inbred generation showed a remarkable uniformity within the individual lines. This indicates that onions are not so heterozygous as might be expected and that there is probably a high percentage of selfing, even under conditions of open pollination. There is some loss of vigor, but this is not marked even in the second inbred generation. Similar results have been attained

by Kotowski (1926) with the variety Zittauer. It has been noted that within the inbred lines there is greater uniformity in size, shape, time of maturity, length of rest period, and color of the bulb; in color, diameter, bloom, amount, and texture of the foliage; and in number, diameter and height of the seed stalks, and many other characters. When desirable strains have been isolated, they are multiplied under open-pollinated conditions.

Seed Production

Seed is produced in most of the large onion-growing regions of the United States, but the main seed-growing areas are in California. The mother bulbs are grown both on muck and sediment soils and in about the same manner as those for market, except that the seed is sown some-

Fig. 11.—Onion seed field in bloom. Delta region of California.

what thicker and the bulbs are smaller than when grown for market. Muck soil is desirable for mother-bulb production, because the bulb develops symmetrically. At time of harvest, the off-type bulbs are culled out and sold for consumption. Mother bulbs of the standard storage types are planted in California in November or early December. Varieties such as California Early Red, which do not keep well in storage, may be planted as early as September. The bulbs are set in furrows about 3 feet apart and spaced 4 to 6 inches apart in the row. They are usually distributed in the furrows from a wagon and later set upright by hand. The bulbs are not covered until they have rooted and a final rogueing has been given. If planted early, a good root development is made during the winter, although the top growth may be small. The seed stalks appear in late February or March, the fields are in full bloom in May and

June, and the seed heads are harvested in July or August. In harvesting, the stalk is cut by hand just below the seed head; the heads are dropped into a sack suspended from the shoulders of the cutter. When the sacks are full, they are dumped into larger bags or into seed-tight wagon boxes. They are than hauled to large canvas sheets and spread about 4 inches deep to dry. The heads are stirred daily until dry enough to be threshed. The seed is extracted by means of large wooden rollers or by specially constructed threshing machines. After most of the chaff has been removed by fanning or screening, the seed is washed to float off the chaff and light seeds. The final cleaning, however, is usually given in the seed mill, where modern seed-cleaning machinery is used to remove all foreign matter and light seeds. According to growers, a fair yield of seed for yellow, brown and red varieties is 300 pounds to the acre and for white varieties, 200 pounds. Yields as high as 1,500 pounds have been reported.

Diseases

Onion Smut (*Urocystis cepulae*).—This disease is present in all of the northern onion-growing sections. It does not occur, however, in the South. Affected seedlings show a slight curvature of the cotyledon accompanied by some enlargement of the affected part. When the spores are mature, the dark-colored sori are very conspicuous, and the host tissue above the sori dries and splits, allowing the chlamydospores to escape. The infecting hyphae enter the host by boring directly through the epidermis. In the host they are confined to the intercellular spaces. Many severely affected seedlings die when they are 3 to 5 weeks old; others may survive until midseason or harvest, but very few ever outgrow the disease. Smutted bulbs do not rot in storage, but they do shrink more rapidly and are more subject to the attack of other organisms than healthy ones.

The absence of onion smut in the South is probably due to a combination of environmental conditions and cultural practices. In the South, the seed is usually sown in late summer or early fall when the temperature is high, while in the North it is planted in early spring when the temperature is low. Onion plants are susceptible to infection only in the seedling stage. According to Anderson (1921), infection may take place about the second day after the seed starts to germinate, and the seedling is susceptible until about the time the first leaf emerges from the cotyledon. Walker and Wellman (1926) find that infection takes place at temperatures as low as 10 to 12°C. and occurs regularly at 25°C. but that as the temperature increases above that point the amount of disease rapidly declines until, at 29°C., it is completely inhibited. High temperatures do not cause a corresponding slowing up in the growth rate of the host plant. In the South, onions have only a short period of susceptibility, and the high

temperatures prevailing at the time of germination inhibit entirely or greatly retard the growth of the smut organism.

The fungus is probably able to exist in the absence of onions and grow in the soil for years.

If infection occurs near the knee of the cotyledon, the latter may mature or die before the mycelium has reached the growing zone through which the parasite gains entrance to the leaves. If infection occurs at or near the stem plate, the growing hyphae soon penetrate the embryonic region from which the leaves arise. In this meristematic tissue, the parasite continues to vegetate and infects each successive leaf as it arises from the growing point.

Control.—This disease may be controlled in any one of the three following ways:

Sanitation.—Special caution should be used to prevent the introduction of the disease by means of onion refuse, sets, farm implements, or other means to uninfected soil. A good practice is to burn the refuse from the storage houses.

Avoidance.—Green or dry sets free from smut will not become infected when planted on soils containing smut.

Formaldehyde Drip.—When seed is sown on infected soil, the best method of control is to apply formaldehyde solution in the row at time of seeding. A solution of 1 pint of formalin in 16 gallons of water is used at the rate of 200 gallons per acre. Seed drills equipped for this purpose are in use.

Mildew (*Peronospora schleideniana*).—Onion mildew is common in most parts of the United States. The first indication of mildew is a violet furry covering on the outside of the leaf, and this is especially conspicuous when the foliage is wet with dew. In 1 or 2 days, large areas of the leaves or seed stalks become pale green, then yellowish, and finally the diseased parts collapse. In the seed stalks, the lesions weaken the stem so that it falls over before the seed is mature.

According to Whetzel (1904), the branched mycelia of the fungus grow in the intercellular spaces of the mesophyll and also push through between the closely packed conductive cells. The haustoria of the mycelium penetrate the cell walls and absorb food. A mycelial thread near a stomate may grow out through it and form the conidiophore, which produces the vegetative spores, or conidia. It has been estimated that there may be 140,000 conidia produced per square inch of onion leaf. When mature, the conidia are carried to healthy leaves and plants by air currents and other means. If moisture is present, they germinate at once. The entire cycle from conidia to conidia requires but a few hours, a fact which accounts for the rapid spread of mildew. The conidia live only a short time, even under the most favorable conditions.

Within the host tissues, the sexual stage of the fungus occurs, resulting in oospore formation. These oospores withstand heat, cold, and desiccation and are probably the only means of perpetuating the fungus from year to year. The oospores are formed within the tissues of the host and are liberated when the onion leaves and seed stems decompose. In the spring, when the weather becomes warm, they germinate and infect the onion crop.

Weather conditions are an important factor in determining the extent and severity of mildew. Heavy dews, cloudy, foggy, and rainy weather, especially if the days are warm, favor the rapid spread of mildew. Where rains occur during the summer, this disease is most often destructive. In California it is usually most destructive to the onion-seed crop. The injury to the seed crop depends upon the stage of development at time of infection. Mildew may appear on the leaves in early spring and then disappear for the remainder of the season if the weather is dry. Later infection may destroy the primary seed stalks, while the secondary ones may mature a good crop of seed. If the conditions remain favorable for the spread of mildew, the secondary seed stems may also be destroyed.

Control.—Mildew may be controlled as follows:

Moisture Control.—Good field aeration should be facilitated (*a*) by planting onions on well-drained grounds, (*b*) by running the rows in the same direction as the prevailing winds, and (*c*) by avoiding windbreaks or other protections.

Crop Rotation.—Onions should not be on the same ground oftener than once in 3 or 4 years.

Sanitation.—Diseased tops contain the resting spores of the disease and therefore should not be carried to disease-free soil. Mother bulbs should come from fields free from mildew.

Spraying.—A 4:4:50 Bordeaux spray has been used to some extent. When used, 3 pounds of resin fish-oil soap is added to each 50 gallons of spray to make it adhere. Several applications are needed throughout the season to cover the new foliage as it appears.

Onion Smudge (*Colletotrichum circinans*).—This disease is widely distributed, having been widely disseminated by the use of infected sets. It affects white varieties chiefly. It is characterized by small, dark-green to black dots on the outer scales; these dots are often arranged in concentric rings. It causes little shrinkage in storage but lowers the market value of the crop because of the smudgy appearance which it gives. If, however, the bulbs are stored without being dried and cured thoroughly, the disease may cause considerable loss.

The fungus lives on onion scales or bulbs in the soil over winter, and consequently it may increase where onions are grown continuously. When the weather is moist and warm, the disease spreads rapidly. According to Walker (1923), the white varieties are very susceptible to

onion smudge, while the colored varieties are highly resistant. The pigmented outer scales of the latter apparently serve as a barrier to the entrance of the parasite. The pigments are present in the cell sap in the outer epidermal layer, especially in the dry outer scales, and at least a portion of the pigment in these is readily soluble in water. Walker showed that water extract of dry outer pigmented scales causes abnormal germination and retards growth of the fungus, while that from dry outer white scales does not. Essentially the same results were obtained with the yellow as with the red scales. Something present in the dry outer scales of colored bulbs and closely associated with or identical to the red and yellow pigments is apparently the chief factor causing resistance.

Control.—To keep smudge under control (1) crop rotation should be practiced, (2) diseased bulbs or refuse from the storage house should not be carried to non-infected soil, (3) the bulbs should be kept dry while curing in the field, and (4) they should be stored in a dry, well-ventilated storage house, where the temperature can be kept just above 0°C.

Neck Rot (*Botrytis allii*).—In most of the important onion-producing states this disease causes losses in field and storage. On the leaves, small white spots become apparent, enlarge, and frequently elongate in the same direction as the leaf. Immediately surrounding this infection, the tissue may look yellowish and water-soaked. On the necks appear tufts of conidiophores bearing smoke-grey conidia. Upon the bulbs in storage black sclerotia are visible. The sclerotia are usually found at the necks of the bulbs singly or in the form of sclerotial crusts which may encircle the neck. The disease may pass the winter on the onion bulbs and in the soil.

Control.—White varieties suffer more from neck rot than colored ones. There appears to be but little difference in the resistance of the red and yellow varieties. To keep neck-rot under control, (1) mature the crop early; this can be accomplished by proper selection of seed stock and good cultural practices; (2) provide good field aeration; (3) prevent wounding of the bulbs; (4) dry the bulbs well before storing. Onions should not be stored in bags or bins, if neck rot is prevalent; (5) provide good ventilation in storage; (6) hold the storage temperature at about 0°C.; (8) diseased onion bulbs and refuse should not be carried to non-infected fields; (9) select mother bulbs free from this disease. Walker (1925) states that neck rot may be largely prevented by thoroughly desiccating the neck tissue of the bulbs within the first 2 to 3 weeks after harvest. This may be accomplished by exposing the bulbs to higher temperature, exposing them to forced air currents, or a combination of the two methods.

White Rot (*Sclerotium cepivorum*).—This disease has been reported as present in Oregon, Virginia, and Kentucky. It attacks the common onion, Welsh onion, leek, garlic, and shallot. According to Walker (1924), the first symptom of the disease is a yellowing and dying back of

the tissue, beginning at the tips of the leaves and progressing downward. The rate of the plant's decline depends largely upon environmental conditions. Both roots and leaf bases are attacked. The roots are gradually destroyed, and there is a semi-watery decay of the scales and an abundance of superficial, white, fluffy mycelium. Sclerotia form early and are black, spherical, hard, and not over ½ millimeter in diameter; they form either on the surface or are embedded in the tissue. If infection of the bulbs occurs late and is carried into storage, decay will continue. The fungus probably overwinters in the form of sclerotia, which germinate when the temperature and moisture conditions become favorable In the absence of host plants the fungus is known to remain viable in the soil for several years. Walker (1926) finds that the disease progresses most rapidly at temperatures of 10 to 20°C. The disease is increasingly retarded above 20°C.; and at 24°C. or above it, is inhibited. In the soil used by Walker, the most rapid development of the disease occurred when the soil moisture was kept at about 40 per cent of the water-holding capacity. At 20 per cent of the water-holding capacity, the growth of the onion plant was accelerated, but infection was reduced. In the North, the most favorable time for the rapid progress of the disease is during the first half of the growing season. In the South and in the Pacific coast sections, the ideal conditions for the development of the disease probably continue over a much longer period. The disease spreads chiefly by attacking onion bulbs, bottom sets, seedlings, and garlic. As far as is known, control methods have not been developed. Growing seedlings and sets on non-infected soil for transplanting will help prevent the spread of the disease. A long rotation will no doubt also help to reduce the amount of injury.

Insects

Thrips (*Thrips tabaci*).—This insect is widely spread in North America. It chafes the epidermis from the green leaves and sucks out the cell contents, causing the leaves to take on a silvery appearance and later to curl and die. The adult is about $\frac{1}{25}$ inch long and pale yellow tinged with black. The eggs are laid singly just beneath the surface of the leaf and hatch in about 4 days.

The severity of an attack by thrips varies from year to year, depending largely upon climatic conditions. A precipitation below the normal and temperatures above the normal seem to favor thrips epidemics. High temperatures in early spring probably increase the number of generations.

Control.—Certain insects, such as the spotted and the convergent ladybird beetle, the insidious flower bug, and the larvae of the syrphus fly prey upon the thrips. Driving rains frequently destroy great numbers of them.

Chittenden (1919) recommends the use of a soap-nicotine-sulfate spray, but in Iowa it was found that this spray did not kill the eggs in the leaf or the nymphs in the soil or within the leaf sheaths. Many of the winged adults escaped also. Campbell (1922) recommends the use of a nico-dust containing 5 per cent nicotine sulphate or Black Leaf 40. As high as 40 pounds per acre may be needed, especially if the onions are large and the dust drifts away quickly.

Thrips are difficult to control by sprays or dusts. The latter are also very expensive; and for this reason, preventive measures should be used as much as possible. The cultivation of waste places and the cutting and burning of grass and weeds where cultivation is not possible will destroy the hibernating forms. The thrips should be controlled in greenhouses during the winter, so that they will not infect the neighboring fields in the spring. Multiplier onions or onion sets should not be planted adjacent to fields which are to be seeded to onions later, as they usually serve as an early breeding ground for thrips. Early plantings should be made, so that the plants will be well established before the attacks occur. Deep plowing should be practiced in the fall to bury the refuse containing the insects. The plants should be kept growing by applying plenty of water and readily available manures. If handled properly, onion plants will often outgrow a rather severe attack of thrips.

Onion Maggot (*Phorbia ceparum*).—The onion maggot occasions serious damage in many important onion-producing sections. Plants are attacked at all stages of development. In the young seedling, the maggots tunnel into the heart of the plant, causing it to die; in older plants, they are usually found in the lower part of the bulb. Tunneling is ordinarily followed by secondary infection with various bacteria and fungi, which cause a rapid decay of the bulb.

The maggot is a white, or yellowish, larva, blunt behind and tapering to a point at the head. The pupae are reddish brown. The adults are medium sized, greyish-brown, humpbacked flies, sluggish in their movements and rather weak fliers. The eggs are small, white, and oval.

Control.—As the most satisfactory method of control, Lovett (1913) recommends the use of a trap crop of onions. For this purpose, the best scallions or discards of the previous years' crop are retained. At time of seeding, every one-hundredth row is left vacant. When seeding is finished, the cull onions are set in the vacant row. These onions make a large foliage development upon which the adults lay their eggs during the early part of the season. They are usually removed when the largest number of first-generation maggots are present, placed in some maggot-proof container, and then destroyed by burning or treating with oil.

The poison-bait method is also recommended by some as a means of control. The formula recommended by Lovett is as follows: sodium arsenite, ¼ ounce; molasses, 1 pint; water, 1 gallon; chopped onion, ½

pound. This bait is placed in the field in shallow pans; about 24 are needed for each acre of onions. One gallon will supply 24 cans for one week. After the adult flies emerge, it is about 10 days before they start to lay eggs. During this pre-oviposition period, the flies are active and are readily attracted to the bait. It is desirable to get the bait in the field before oviposition starts.

SECTION B. GARLIC

Garlic is a perennial herb with a strongly penetrating, alliacious odor. It is used in greatest amount by the southern Europeans. According to Sturtevant, it was well known to the ancients and may be native to the plains of western Tartary, whence it has spread throughout Asia, North Africa, and Europe. It was probably introduced into the United States sometime during the latter part of the eighteenth century.

The garlic bulb is composed of a large number of bulbils, or cloves, which are enclosed by a common scale. The leaves are flat, and the scape is terminated by a single umbel, which usually produces both bulblets and seed. Until recently, most of the garlic used in the United States was imported, but at present there is sufficient grown in this country to supply the demand. The main producing section is in central California, in San Benito, Santa Clara, Monterey, and Santa Cruz Counties. Most of the garlic is grown on heavy soil. Planting is done in November, December, or January. The cloves are spaced 2 to 3 inches apart in rows 16 to 18 inches wide; they are set just deep enough to hold them erect. It requires about 600 pounds of bulbs to plant one acre. When the tops begin to turn yellow—usually in July or early August—the plants are pulled and set close together with the tops covering the bulbs to prevent sun scald. When dry, the tops are removed and the bulbs thrown in large piles until they are sacked.

SECTION C. LEEK

According to Sturtevant, the leek is a native of Switzerland, although at present it is found growing wild in Algiers. It has been cultivated from very early times. Its date of introduction into England is given as 1562, but in all likelihood it was cultivated there much earlier. Leeks were probably introduced into the United States by the early settlers. They are not, however, used extensively in this country. Leek is a biennial but does not form a bulb. The root system is fibrous and similar to that of the onion. During the first year, the stem is plate-like; from it arise the leaves, which have solid, broad-keeled blades with the halves flat. The edible part of the leaf is the sheath, which is whitened by banking with earth and then eaten as green onion. The second year, a single, long, solid scape, 3 to 4 feet or more high, is formed, and this is terminated by a single umbel containing usually several thousand flowers. At first, the

buds are protected by a spathe, which is considerably prolonged. The flowers are pinkish, and pollination is chiefly by insects. The method of planting is similar to that of onion: Rows are 2 to 2½ feet apart, and the plants are thinned 4 to 6 inches apart in the row. As the plants grow, the soil is banked against them to whiten the sheaths. The plants usually mature in the fall and are then marketed in the same way as green bunch onions.

Most of the leek seed is grown in California. It is usually sown in the spring, in rows about 3 feet apart. The plants are not reset but are allowed to winter over in the field where sown. The second year, seed is produced. The methods of handling, threshing, and cleaning are the same as for onion.

FIG. 12.—Leek inflorescences. On the right are shown the long bracts covering the buds.

SECTION D. SHALLOT

According to Sturtevant, the shallot is now cultivated everywhere, but it has not been established that it occurs in the wild state. The shallot is mentioned in most of the early botanies. The plant is a small perennial and seldom produces seed; the bulbs are compound and break up into bulblets, which cohere at the base. The leaves are slender. The bulblets are planted in the early spring and are handled about the same as onion sets. The bulbs are harvested when mature; they are somewhat milder than most other species of cultivated *Allium* and are used mainly for seasoning.

SECTION E. CHIVES

The chive is not grown to any great extent in America. In the European gardens, chives are cultivated for the leaves, which are used in

salads, soups, and for flavoring. The plant is perennial and grows in compact tufts or clusters. The leaves are small and hollow. Seeds are seldom produced, so propagation is usually carried on by division of the clusters.

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CHAPTER III

ASPARAGUS

Until recently, asparagus has not been used in large amounts. Within the last 20 years, however, the industry has developed very rapidly, and asparagus is now being grown in the home garden and as a market-garden and truck crop. Those states producing large amounts for shipping fresh are California, Illinois, New Jersey, and South Carolina. California leads in the production of asparagus for canning.

Taxonomy.—The genus *Asparagus* comprises about 150 species spread throughout the temperate and tropical regions of the Old World. All species of *Asparagus* are perennial, have fleshy or tuberous roots, and possess cladophylls, which function as leaves. There are many species cultivated for ornamental purposes; *A. officinalis* is the only one cultivated as a food plant.

Historical.—According to Sturtevant, the native home of asparagus is Europe—the Caucasian regions and Siberia. It is found growing wild and in great abundance today in parts of Russia and Poland. It was used by the Greeks and Romans both as a medicinal and food plant and, from published historical accounts, it seems to have been in cultivation for approximately 2,000 years. There is very little record of the spread of asparagus throughout Europe and other foreign countries. It was no doubt brought to the United States by the colonists and grown by them along the Atlantic seaboard.

Plant Characteristics

Roots.—The underground portion of the asparagus plant consists of rhizomes, fleshy roots, and fibrous roots. The fleshy roots may spread laterally a distance of 10 or 12 feet as they grow outward and downward. They will grow to a depth of at least 8 feet and may go deeper unless a permanent water table is encountered at a higher level. The fleshy roots being covered with root hairs, function both as storage and absorptive organs. The fleshy roots continue to elongate for a number of years, their exact life duration being unknown, but they are not as short-lived as has often been claimed. New fleshy roots arise each year just back of the terminal buds of the rhizomes; from these, fibrous roots arise which function as absorptive organs only. The fibrous roots die in late fall at the close of the growing season, and new ones develop the following spring. It is chiefly within the fleshy roots that the food supply is stored for the

FIG. 13.—Five-year old asparagus plant from time of transplanting showing aerial stems, rhizomes and fleshy roots.

production of the commercial crop the following year. To determine the amount of food utilized in spear production, Wichers and Tollens (1910) analyzed the fleshy roots in April before the beginning of the cutting season and in July after the harvesting season. The most marked change in composition is the reduction in sugar content. Table 11 shows very clearly that the marketable spears are produced primarily at the expense of the sugars, although other materials than sugars are also used.

TABLE 11.—COMPOSITION OF ASPARAGUS ROOTS, IN PER CENT OF DRY WEIGHTS (*Wichers and Tollens*, 1910)

	Crude fiber	Crude fat	Crude protein	Ash	Sugar	Pentosan
April	8.72	0.72	14.13	12.20	36.80	6.25
July	13.54	1.10	16.56	11.77	23.19	7.73

Stem.—The asparagus plant has underground stems (rhizomes) and aerial stems arising from them. At the base of each aerial shoot, there are one or more lateral buds separated by very short internodes. The branches of the underground stem grow outward and upward; the deeper the plant is set, the more nearly vertical is the growth of the rhizome toward the surface. The branches of the rhizome grow 1 to 2 inches each year. The rhizomes of the young plants make more rapid growth than those of older ones. They continue to elongate and branch, and a 15-year-old plant may have a rhizome spread of 2 feet or more. After the cutting season, during the summer and fall, most of the buds are formed which produce the edible spears the following spring.

The aerial stems arise from buds located some distance back of the terminal end of the rhizome. These stems are the spears, cut in the spring for market or canning. The principal anatomical regions of the spear are: (1) epidermis, (2) cortex, (3) pericyclic fibers, (4) ground parenchyma, and (5) vascular bundles. The outer wall of the epidermal cells is somewhat cutinized and thickened. The cortex is a zone of tissue of varying width, consisting of rather large, thin-walled, loosely fitting chlorophyll-containing cells. The pericyclic-fiber zone is composed of long, tapering, thick-walled, close-fitting cells, without intercellular spaces. The walls of old pericyclic fibers have deposited within them a material known as "lignin," which gives hardness to the tissue. The degree of lignification increases with age, and the toughness of the basal part of the spear is mainly due to the lignified walls of these fibers. In the tip of the asparagus spear, the walls of the fibers are thin; there is no deposit of lignin within them, and there is no sharp line of demarcation between the parenchyma tissue of the cortex and that which is destined

to develop into pericyclic fibers. As the stem grows older, the fiber region becomes more and more distinct. The ground parenchyma is within the pericyclic-fiber zone. In this region are scattered the vascular bundles. The cells of this tissue are large and thin-walled and are separated by large, intercellular spaces. The vascular bundles near the fibers are the youngest and smallest. Each vascular bundle appears in cross-section

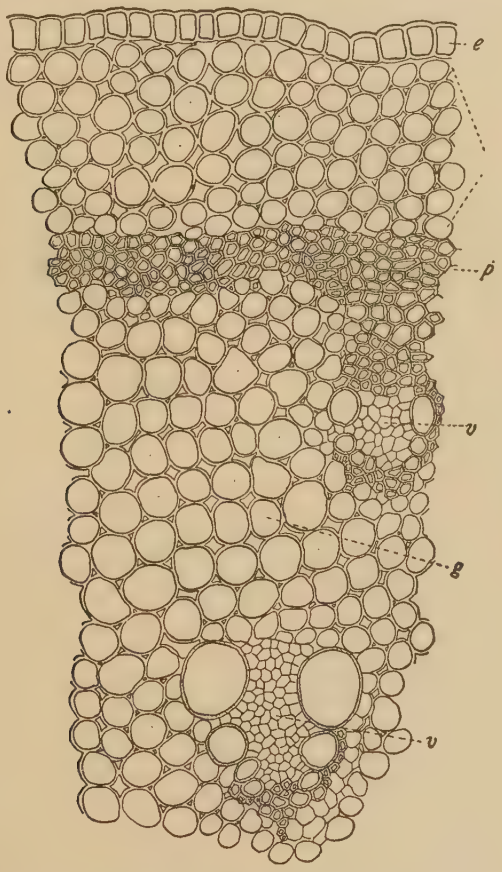

FIG. 14.—Cross section near the base of an asparagus spear. e, epidermis; c. cortex; p. pericycle; v. vascular bundle; g, ground tissue. (Bisson *et al.*, 1926.)

as a V-form, with the apex toward the center of the stem. The tracheal tubes form the arms of the bundle, and between them are the phloem elements. Associated with the tracheal tubes are thick-walled wood fibers. As the spear grows older, the outer wall of the epidermis becomes thicker and more heavily cutinized, the fiber zone becomes more distinct, and the fiber walls become thicker and more heavily lignified; there is also an increase in the number of lignified tracheal tubes and a thickening of

their walls. There are many more lignified elements at the base than at the tip of the spear.

Analyses by Morse (1916) show an increase in percentage of sugar in the spears as the cutting season progresses and a decrease in the protein and lignin. Morse is of the opinion that the larger amount of sugar late in the season is due to increased photosynthetic activity in the spear. The decrease in lignin is probably due to the more rapid growth at the prevailing higher temperatures.

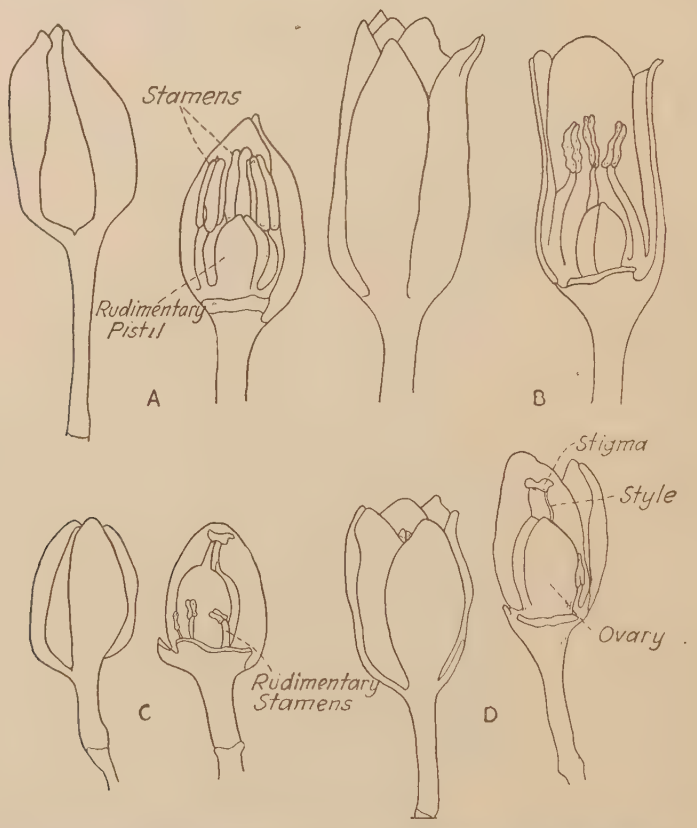

FIG. 15.—Staminate and pistillate flowers of asparagus. A. Staminate flower buds. B. Staminate flowers at time of anthesis. C. Pistillate flower buds. D. Pistillate flowers at time of anthesis. Note the rudimentary stamens. (*Robbins and Jones*, 1925.)

After the cutting season is over, the stems are allowed to develop, forming the so-called fern. The cladophylls (stems), which perform the functions of leaves, are clustered in the axils of the scale-like leaves. Carbohydrates manufactured during the summer are translocated to the fleshy roots and rhizomes.

Leaves.—The true leaves are scale-like and are found at the nodes subtending the main branches and the cladophylls.

Flowers.—Asparagus is normally dioecious. The flowers occur in the axils of the scale leaves. The early stages of the development of staminate and pistillate flowers appear to be similar. All flowers in the primordial stages bear both sets of sex organs and hence are potentially hermaphroditic. According to Robbins and Jones (1925), the first evidence of the flower is a slightly rounded protuberance in the axil of a scale leaf. The primordia of the three outer perianth segments are the first to appear; these are followed in turn by the primordia of the three inner perianth segments, the outer whorl of stamens, the inner whorl of stamens, and, finally, the carpels. In each whorl, the floral organs are in threes. During later stages of floral development, there is, except in rare cases, an abortion of either the male or female sex organs. In staminate flowers, the pistil fails to attain normal size. The ovules of the staminate flowers seldom develop farther than the primary archesporial stage; the integuments seldom attain a size sufficient to enclose the ovule. In pistillate flowers, the anthers do not attain normal size, the filaments are short, and the immature pollen mother cells disintegrate.

Pollination.—Asparagus flowers are almost entirely insect-pollinated. Various species of bees are the chief pollen carriers; according to Norton (1913), the honey bee plays a prominent part. A considerable amount of nectar is produced. Pollination by wind is probably negligible, as the pollen does not become powdery until the flower dries. On sunny days, most of the anthers dehisc in the morning. In his breeding work, Norton enclosed in glassine bags the branches of the pistillate plants which were to be artificially pollinated; these bags prevented insect visitation and the introduction of undesirable pollen. When the pistils were hand-pollinated with fresh pollen, a good set of seed was obtained under the bags.

Fruit and Seed.—The fruit of asparagus is a small, spherical berry. When young, it is green in color but turns red upon maturity. The fruit has three locules. In case of a perfect set, each fruit has six seeds—two in each locule.

Seed Development.—According to Robbins and Borthwick (1925), at time of pollination, the inner integument of the ovule consists of two cell layers and the outer integument, of from five to ten. The seed coat reaches its maximum thickness about 16 days after pollination. During this time (1) there is an increase in size of all cells of the integuments; (2) there is a pronounced thickening of the outer wall of the epidermal cells; (3) the two cell layers of the inner integument become easily discernible; (4) the cell contents of the inner cell layer of the inner integument become yellowish and granular, and a membrane is developed in its inner wall adjacent to the nucellus; (5) the inner boundary of the outer integument also develops a thin membrane. These two membranes give a pronounced fat reaction to microchemical tests. Later, there is a

decrease in the thickness of the seed coat; the outer wall of the epidermal cells becomes very thick, and their lumina almost filled with a dark-brown substance. Covering the outer surface of the epidermal cells is a thin membrane, probably pectic in nature. By the thirtieth day after pollination, the two fatty membranes are closely compressed, and in the mature seed they are almost indistinguishable. These integumentary layers function as semipermeable membranes, permitting the intake of water but inhibiting the entrance of various salts.

Five days after pollination, a few free endosperm nuclei are located at the micropylar end of the embryo sac; 10 days after pollination, endosperm nuclei are distributed on the periphery of the embryo sac, embedded in a thin layer of protoplasm. Wall formation in the endosperm begins about the thirteenth or fourteenth day. Endosperm development proceeds inward; and about 3 weeks after pollination, the endosperm fills the embryo sac. At this time, the embryo is very small. Food storage in the endosperm starts when that tissue is completely formed and continues until the seed is ripe. Hemicellulose is stored in the walls; and oil and protein, in the lumina. Cell-wall thickening takes place first in the innermost cells and progresses outward. As the walls thicken, narrow canals are left at intervals, those of adjoining cells coinciding. The middle lamella is pectic in nature.

About 10 days after pollination, the proembryo consists of an irregular-shaped, massive suspensor and a few-celled embryo. By the second week, the endosperm has completely surrounded the free end of the embryo. By the third week, the embryo is elongated and many-celled; a root cap is present, and many of its cells contain starch. Immediately surrounding the embryo are rows of thin-walled, compressed endosperm cells. During the fourth week, there is a rapid increase in the size of the embryo. A lateral depression develops a short distance back of the root cap, within which the stem growing-point is located. The hypocotyl is short, and the cotyledon elongates so that the mature embryo is almost the full length of the seed.

The main mass of the mature seed is composed of endosperm cells. The mature embryo is slender and completely embedded in the endosperm. By far the greater portion of the embryo is cotyledon, which functions as the absorptive organ during germination.

Secondary Sex Characters in Asparagus.—Studies in California have shown that there are significant quantitative differences between staminate and pistillate asparagus plants. As shown in Table 12, the staminate plants express their sex much earlier in life than do pistillate plants. The first staminate plants to flower preceded the pistillate about a month. In a population of 2,400 plants, 743, or 31 per cent of all the plants, had expressed their sex by Sept. 3.

TABLE 12.—TIME OF SEX EXPRESSION OF SEEDLING PLANTS AT DAVIS, CALIFORNIA, VARIETY PALMETTO
(*Robbins and Jones*, 1925)

Number of plants observed	Sex	Plants in bloom or fruit (1923), dates										
		7/2	7/7	7/11	7/13	7/16	8/2	8/4	8/7	8/11	8/27	9/3
2,400	Staminate	15	26	37	88	127	173	201	398	450	507	530
2,400	Pistillate	0	0	0	0	0	3	17	47	86	120	213

Before the plants were killed by frost, many more were in bloom. In the North, asparagus plants do not bloom the first year.

The first flower-bearing shoot usually appears earlier in the life of the staminate than in the pistillate plant. In staminate plants the first flower-bearing shoot varied from the fifth to the eleventh (average, 7.2 for 149 plants). In pistillate plants, the first flower-bearing shoot varied from the fifth to the fourteenth (average 8.5 for 80 plants).

Measurements of the 149 staminate and 80 pistillate plants above show that the average height of the first flower-bearing shoot of staminate plants is 47.8 centimeters, while the average height of the first flower-bearing shoot of pistillate plants is 62.4 centimeters—a difference of 14.6 centimeters in favor of the pistillate.

Records taken the first and second year after transplanting show that the staminate plants produce (1) more stalks, (2) a greater total height of stalks, and (3) a greater weight of green tops than the pistillate.

TABLE 13.—COMPARISON OF TOP GROWTH OF STAMINATE AND PISTILLATE PLANTS
(*Robbins and Jones*, 1925)

	Average number of stalks per plant, November, 1924	Average number of stalks per plant, October, 1925	Average total height of stalks per plant, May, 1924	Average weight of green tops per plant, November, 1924	Average weight of green tops per plant, October, 1925	Average weight of green tops per plant berries deducted, October, 1925
	Number	Number	Inches	Pounds	Pounds	Pounds
Pistillate.....	6.15	5.4	53.6	0.77[1]	2.4[1]	1.5
Staminate.....	9.30	8.9	63.3	0.82	2.8	2.8

[1] Weight of berries not deducted. When the weight of the berries is not deducted, there is no significant difference in weight of tops between staminate and pistillate plants.

One year's data by Green (1890), in Ohio, on 50 staminate and 50 pistillate plants show that the staminate outyielded the pistillate plants by 50 per cent. The difference in favor of the staminate was greater during

the early than during the latter part of the cutting season. Tompson (1923) reports experiments with the Washington variety in Massachusetts, which show that the staminate plants produce more spears but do not average as large as those from pistillate plants. In a later report on the same plantation, Tiedjens (1924) states that the staminate outyield the pistillate plants by 25 per cent. Over 1,000 plants were considered by these two experimenters. Data presented by Robbins and Jones (1925, 1926) substantiate the conclusions of previous investigators: (1) that the staminate plants outyield the pistillate; (2) that the difference in daily production is greater during the early than during the later part of the cutting season; (3) that the pistillate are, on an average, larger than the staminate spears. In Table 14, a summary of the results are given for staminate and pistillate plants for the first two cutting seasons.

TABLE 14.—COMPARISON OF PERFORMANCES OF STAMINATE AND PISTILLATE ASPARAGUS PLANTS. BED PLANTED 1924. APPROXIMATELY 2,600 OF EACH SEX CONSIDERED

(*Robbins and Jones*, 1926)

	Staminate	Pistillate
Yield of spears, 1925 (Feb. 25 to Apr. 1)		
Number of spears per plant	2.98	1.95
Weight of spears per plant, grams	55.87	42.66
Weight of single spear (8½ inches), grams	18.74	21.90
Yield per acre, pounds	372.20	278.40
Yield of spears, 1926 (March 5 to Apr. 25)		
Number of spears per plant	15.68	8.61
Weight of spears per plant, grams	372.75	238.78
Weight of single spear (8½ inches long), grams	23.77	27.73
Yield per acre, pounds	2,556.00	1,614.00

Sex Intergrades.—Observations in California show that hermaphroditism is very rare and is limited to a relatively few flowers in plants which are predominately staminate. Similar observations are reported by Norton (1913) in Massachusetts.

Sex Ratio.—A large number of counts made (Robbins and Jones 1925) in commercial-asparagus fields in California show that there are about equal numbers of staminate and pistillate plants.

SOIL AND CLIMATE

Soil Preferences.—The best soil types in which to grow plants for transplanting or in which to establish permanent plantations is either light, sandy loam or muck. These soils are open and porous and facili-

tate root penetration and elongation. One-year-old plants for transplanting may be dug with a minimum amount of injury; while on heavy soils, many of the rhizomes are injured, and a large percentage of the fleshy roots are lost in digging. As these roots contain the reserve food supply, their loss retards the early growth of the plant after resetting. When early growth of spears is necessary for profitable production, as in the Imperial Valley of California, in Georgia, South Carolina, New Jersey, and, to a certain extent, in the Delta region of California, a soil that warms rapidly in early spring should be selected. Asparagus will grow well on soils that have a salt content too high for the production of most other crops. This characteristic makes possible the utilization of land which has a high sodium-chloride content. Rudolfs (1927) added rock salt to asparagus at rates of 150, 300, and 500 pounds per acre, in addition to barnyard and poultry manure. He found that there was an increase in the number of stalks produced after the cutting season, as the amount of salt applied was increased. Forbes (1914) found an asparagus plant surviving in a soil that contained 0.65 per cent sodium chloride and 0.18 per cent of sodium carbonate, this being almost the limit of tolerance.

Temperature.—The optimum temperature for the growth of asparagus has not been determined. Working (1924) found that spears were produced at 15°C., if the soil was kept fairly wet; but that at 17°C., there was no sprouting, if the soil was only barely moist. He did not make an attempt to find the lowest temperature at which spears could be produced. Spears that had already started grew at a soil temperature as low as 8.7°C., with an air temperature several degrees lower. This observation was over a short period only but indicates that after growth has once started, it will continue at a fairly low temperature. Bisson, *et al.* (1926), found that there was some growth at as low as 1°C. in harvested spears standing in water and that it was continuous over the 7-day period. Working (1924) states that the time of branching of the aerial stems is chiefly a function of the temperature. Spears of a plant growing at 35 to 40°C. began branching when they were only 6 to 8 centimeters high; but at 15°C., they reached a height of 75 to 100 centimeters before branching.

Moisture.—Moisture of the air does not seem to be an important factor, but soil moisture must be high for root elongation and also to start the spear into growth.

Culture

Growing and Handling the "Crowns."—If a large acreage is to be planted, it is better to grow "crowns" (roots and rhizomes) than to buy them. (1) To do so usually costs less; (2) the grower is acquainted with the source of seed; (3) care can be taken to grow large crowns by proper

spacing and cultural practices; (4) crown selection can be practiced; and (5) planting in the permanent bed can be done shortly after removing the crowns from the nursery.

Seed Treatment.—Asparagus seed germinates very slowly; it is usually 2 to 6 weeks from time of planting until the plants appear above ground. As a result of this, it is often difficult to control the weeds. Two methods have been used to overcome the difficulties incident to the slow germination of seeds; these are: (1) The sowing of quickly germinating seeds, such as those of radish, with the asparagus seeds—the radish plants soon appear above the ground and mark the rows—and (2) soaking the asparagus seed in water to hasten germination.

Borthwick (1925) conducted a number of field and laboratory tests on seed soaking. The most rapid germination in the field was obtained when the seeds were soaked in water for a period of 3½ to 4 days at temperatures of 86 to 95°F. When removed from the water, they should be spread thin on a canvas, until the surface is dry. They should then be planted immediately in moist soil. The advantage of soaking is lost if seeds are planted in dry ground or are exposed to the dry air for a considerable time. Soaking seed for short periods is of little value.

Time, Rate, Depth, and Methods of Seeding.—Seed can be sown in early spring several weeks before the danger of frost is over; 4 to 5 pounds are usually planted to the acre. Best results are obtained when the rows are about 24 to 30 inches apart and the plants, 3 to 4 inches apart in the row, to allow plenty of room for development. If the seeds are dropped in groups of three or four, the fleshy roots become interwoven, and it is difficult to separate them at sorting time. A special effort should be made to drop the seeds one in a place. The proper depth of planting varies with the type of soil. In peat soils, the seed can be planted 2½ to 3 inches deep. There is little advantage in deep planting, except to keep the seed in contact with a permanent moisture supply and thereby insure germination. In sandy loam and light, sandy soils, the seeds should be planted from 1½ to 2 inches deep. They may be dropped into the furrows by hand, or garden drills may be used.

Seed Germination.—In germination, the reserve food of the embryo and the hemicellulose and fat of the endosperm are changed into soluble substances that move to the growing root and the stem tips. The radicle is the first organ of the embryo to appear through the seed coat. After it has attained a length of ¼ to ½ inch, the primary stem appears. The absorption organ of the embryo remains in contact with the endosperm for several weeks, and during this time it increases in size, finally becoming a large, spongy structure, which may completely fill the seed. The time required for the primary shoot to reach the surface of the soil depends not only upon the supply of water and oxygen and upon the temperature, but also upon the depth of planting and the texture of the soil. The

optimum temperature for the germination of the seed is between 25 and 30°C. At 20°C., germination is very slow.

Development of the Plant during the First Season of Growth.—The primary root seldom attains a length of more than 5 or 6 inches; and the primary shoot, 4 or 5 inches. They are both temporary organs and die

FIG. 16.—Seedling development. 1–3. Seminal root and seminal shoot of young seedling. Ten, 14 and 34 days after seeding. 4. Appearance of first secondary shoot and first fleshy root, 54 days after seeding. 5. Seventy-five days after seeding. (*Jones and Robbins* 1924.)

long before the end of the growing season. Figures 16 and 17 show the mode of development of the plant during the first growing season. Throughout the season, there is a rapid increase in the number of fleshy roots but a less rapid increase in the number of secondary shoots. Each shoot which arises from the rhizome during the first year is almost always larger than the one preceding. The larger size of succeeding shoots prob-

ably results, at least in part, from the rapid increase in food supply. The roots penetrate to a considerable depth during the first year. In the asparagus nursery at Davis, California, the fleshy roots had penetrated to a depth of 18 inches by the last of July.

Thinning is difficult and impracticable because of the growth habit of the asparagus plant. After the fleshy root system has begun to develop, the shoot usually breaks off when an attempt is made to pull the plant. If the rhizome remains in the soil, shoots appear again in a few days. After the fleshy roots have started to develop, the only way to thin is to dig out the rhizome; but in doing this, there is danger of injuring adjacent plants. Proper spacing should be given to plants at the time of seeding.

Plants in the nursery are very responsive to soil-moisture variations. The soil about the fleshy roots and rhizomes must be kept moist if the best development is to be obtained. Fleshy roots will not elongate in dry soil. Water should not be added after the early part of September, because when the soil is kept moist, new shoots continue to appear as long as the temperatures are sufficiently high for growth to take place. Shoots appearing late in the fall may make a considerable demand upon the stored food in fleshy roots and rhizomes.

Digging "Crowns."—After tops have been killed by frost, they are cut and burned. The crowns should be turned out with as little injury to the fleshy roots as possible. A mold-board plow may be used or a U-shaped knife that runs underneath the mass of fleshy roots and straddles the row. The knife at the bottom should be at least 12 inches wide and have an upward tilt toward the rear, which will have a tendency to loosen the dirt about the crowns.

Storing.—If the crowns are to be stored for a time, they should be kept in a dry atmosphere at a temperature of about 5°C. They should not be stored for long periods where they may be subject to desiccating winds, as they lose thus a large amount of moisture and when again planted are slow to start into growth. In a comparison of plots planted with desiccated and non-desiccated crowns, Jones and Robbins (1926) found that the latter outyielded the former by 12.4 per cent the first cutting season and 27 per cent the second season. The desiccated crowns were exposed to drying conditions for 53 days, and during this time they lost about 25 per cent of their weight. Extreme desiccation kills also a large number of the buds. On the other hand, if crowns become moist when stored in large piles, they soon begin to heat. The fleshy roots contain a large amount of sucrose, which is an excellent medium for the growth of molds and, with optimum moisture and temperature conditions for the growth of the various fungi, the fleshy roots are soon destroyed. The planting of crowns that have been injured by molding is one of the most common causes of poor stands in the fields.

"Crown" Selection.—Crown selection has not been practiced so generally in the United States as in Europe. Many growers in this country are of the opinion that crown grading does not pay, but most of the work done seems to show that it does not pay to plant the very small crowns. Crowns should be selected which have a small number of relatively large, healthy buds. The fleshy roots should be free from disease and not withered.

FIG. 17.—One-year old asparagus "crown;" used for planting the permanent bed. (*Jones and Robbins*, 1924.)

Myers (1916), of Pennsylvania, reports yields over a period of 6 years for three grades of crowns. The weights of crowns are not given for the different grades, but the No. 1 was largest; No. 2, medium sized; and No. 3, smallest. Planted in the spring of 1908, the asparagus was cut for the first time in 1910. Table 15 gives the acre yields obtained by Myers over a period of 6 years.

TABLE 15.—"CROWN" SELECTION. ACRE-YIELD RECORDS ON ASPARAGUS, 1910–1915 (*Myers*, 1916)

Grade No.	Variety	1910	1911	1912	1913	1914	1915	Average yearly[1] acre yield, pounds	Total acre[1] yield for period, pounds
		Pounds	Pounds	Pounds	Pounds	Pounds	Pounds		
1	Palmetto	1,064	2,908	5,827	6,981	8,167	7,492	5,398	32,391
2	Palmetto	1,141	2,659	5,505	6,484	8,030	7,492	5,219	31,314
3	Palmetto	586	1,181	4,449	5,385	6,943	6,566	4,677	26,810
1	Argenteuil	629	2,011	4,569	5,808	6,751	7,233	4,500	27,003
2	Argenteuil	434	1,747	4,123	5,587	6,800	7,252	4,467	26,810
3	Argenteuil	218	1,075	2,904	3,955	5,476	5,990	3,494	20,925

[1] Corrected to a uniform stand.

There is not a striking difference between the yields obtained from the No. 1 and No. 2 "crowns." In no case, however, have the No. 3's produced so much as the other two grades, even after a period of 6 years.

Planting "Crowns" and Care of Bed during First Year.—Where conditions permit, crowns may be planted any time during the winter. In the North, they are planted in early spring, as soon as the ground can be worked. Crowns should be set as soon as possible after removing from the nursery. Fleshy roots should not be pruned, as the amount of reserve food is thereby reduced and the injured roots will not continue to elongate, because the terminal growing point will have been destroyed. In a comparison of plots planted with pruned and unpruned crowns, Jones and Robbins (1926) found that the latter outyielded the former 8.5 per cent the first year and 14 per cent the second year. The roots were pruned back to 4 inches from the rhizome. Approximately 25 per cent of the crown, by weight, was pruned off. The rows are usually 6 to 8 feet apart, the greater distance being used where the rows are to be ridged for cutting white asparagus. The usual distance between crowns in the row is from 18 to 24 inches. Crowns are planted at depths of 10 or 12 inches in peat soil, 6 to 8 inches in sandy loam, and still shallower in very heavy soil.

Trenches are usually made with a lister or middle breaker and with extensions to carry the dirt away from the furrow. The crowns are dropped in the bottom of the trench with buds up and the fleshy roots extended laterally. They are covered immediately with from 1 to 2 inches of soil. When shoots appear, sufficient soil is moved into the furrow to cover the weeds. Additional dirt is moved into the furrow at each cultivation, so that by midsummer the furrows have been filled.

Intercropping the first year with bush beans, potatoes, peppers, and other low-growing crops is practiced to a considerable extent. The most successful growers, however, regard intercropping as inadvisable.

Care of Plantation during Second and Subsequent Years.—Methods of handling the asparagus plantation vary somewhat in different localities. In the East and Middle West, harvesting is usually started 2 years after planting. The fields are cut for 2 or 3 weeks, as a rule; and the following years, cutting extends throughout the normal harvesting season. In California and Arizona, the beds are usually cut for a short period the year following planting, if the growth of the plants was good the first year. In the second year following planting, the beds are usually cut longer than they are during the first year. Thereafter, they are cut throughout the normal harvesting season. Jones and Robbins (1926a) found that cutting the bed the year following planting did not reduce the second year's production. In those sections of the country where green asparagus is cut for the market and where surface irrigation is not practiced, it is necessary to make a low ridge over the rows to prevent the flooding and packing of the soil. When irrigating during the harvesting season, the water is applied in alternate middles so that the cutters will have a dry pathway.

In the Delta region of California, low ridges are used during the early part of the season or as long as the crop is cut for eastern shipment. When the canning season opens, about the first of April, white spears are desired, and the ridges must be made sufficiently high to allow the asparagus spear to make the desired length entirely below ground. Preparatory to ridging for the production of white spears for canning, the low ridges are often disked down and then re-built to a height of 15 to 20 inches. During the cutting season for the cannery, the ridges must be rebuilt every few weeks. Some growers disk the ridges down to kill the weeds and loosen the soil and then rebuild them, but this method destroys many of the young spears. If the soil is loose and comparatively free from weeds, the ridges are merely built up from time to time to the desired height.

Most of the asparagus acreage of California is located on the reclaimed sediment, peat, and muck lands of the Delta region. A large portion of this area was formerly subject to overflow. The land is now protected from the flood waters by levees. Generally, the surface of the asparagus land is below that of the streams, and irrigation is carried on by siphoning and pumping the water from the streams and sloughs into large ditches that carry it to a system of laterals throughout the fields. The soil is very porous, and when the water is raised in the ditches, the water table is elevated throughout the entire soil area. The water is raised to within a few inches of the surface and is then pumped back until the water level reaches the desired depth of 5 to 6 feet. Level cultivation is given after the cutting season, except in those regions where surface irrigation is practiced. In late fall, winter, or early spring, the dead tops are cut and burned or disked into the soil.

Harvesting.—The spears are cut whenever they are sufficiently long. This may necessitate harvesting every day or every second or third day, depending upon the temperature. When cutting for the fresh market, the spears are usually not cut until they are 6 to 9 inches above ground. Very little white asparagus is sold fresh; the produce markets of the country now demand chiefly the green product. When cutting for the cannery, the spears are cut below ground while they are still white. As soon as the spears break the soil on the top of the ridge, they are harvested. An attempt is made to harvest the spears before they turn green. They are laid in bunches on the top of the ridges, then collected in carts.

Yields and Life Duration.—The profitable life duration of an asparagus bed varies with different climatic and soil conditions. As a rule, it is longer in the North than in the South and longer on heavier than on lighter types of soil. In California, the profitable life of a bed varies from about 10 to 15 years. As the bed becomes older, the ends of the rhizomes approach the surface, and many of the large terminal buds are destroyed in cultivation. The small, lateral buds are then forced into growth, a fact which probably accounts for the large number of small spears in old beds. The average production per acre in California is about as follows:

Year	Yield per acre, pounds	Year	Yield per acre, pounds
First	0	Sixth	4,250
Second	500	Seventh	4,500
Third	1,000	Eighth	5,000
Fourth	2,000	Ninth	5,000
Fifth	4,000	Tenth	4,750
		Eleventh	4,500

Marketing

Market Asparagus.—Asparagus for shipment is handled in much the same way in all the large trucking districts. It may be graded, bunched, and packed on the individual farms or hauled to large central packing houses. Most of the asparagus packed for long-distance shipment is bunched. When brought to the packing shed, the spears are usually sorted by hand into four or five different grades, which are distinguished mainly on the basis of size. The spears are tied in bunches of approximately 2½ pounds and then trimmed to a length of about 8½ inches. The trimmed bunches, until packed, are usually stood in shallow pans in an inch or two of water, which may or may not be iced. When removed from the pan, each bunch is rolled in a stamped, parchment-paper wrapper.

The bunches are then packed in pyramidal-shaped crates, with the butts resting on wet moss. The spears absorb water from the moss and consequently remain fresh during transit. Parchment paper is placed on the bottom of the box also, so that the moss rests upon this paper rather than upon the dry boards of the box.

A method known as "loose pack" is also used to some extent. The spears are not bunched, grading is less rigid, and the cost of packing is reduced. This type of pack seems to be gaining favor for local marketing.

In the Imperial Valley of California, asparagus is precooled before it is loaded into iced cars. In northern California, precooling is not practiced, but the crates are loaded into iced cars as soon as they are packed.

FIG. 18.—Asparagus packed in pyramidal crates ready for shipment.

Chemical Changes in Asparagus Spears after Harvest.—From the standpoint of edible quality, it is important to know what chemical changes take place in the spears after harvest and how temperature influences the composition and the rate of change of the various constituents. Bisson, *et al.* (1926), studied mainly the sugar and crudefiber changes. The spears were stored at temperatures of 1, 6, 14, 25 and 35°C.

While there is a loss of sugar at all temperatures, the rate of loss is more rapid at the higher temperatures. The reducing sugars constitute about 93 per cent of the total sugars. The losses in reducing sugars for the different temperatures parallel those of the total sugars. There is a considerable increase in the crude fiber content of spears during storage, as shown in Table 17.

TABLE 16.—PERCENTAGE OF TOTAL SUGAR IN SPEARS STORED AT DIFFERENT TEMPERATURES. PER CENT OF DRY WEIGHT
(*Bisson, et al.*, 1926)

Period of storage in hours	Original sample	Storage temperatures, °C.				
		1	6	14	25	35
	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
0	24.91					
24	.....	26.69	23.59	22.05	20.09	19.63
48	.....	26.37	24.58	21.49	20.28	16.34
72	.....	24.76	23.63	21.32	18.08	16.75
96	.....	23.91	21.08	18.21	16.41	

TABLE 17.—PERCENTAGE OF CRUDE FIBER IN ASPARAGUS SPEARS STORED AT DIFFERENT TEMPERATURES. PER CENT OF DRY WEIGHT
(*Bisson, et al.*, 1926)

Storage period in hours	Original sample	Storage temperatures, °C.				
		1	6	14	25	35
	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
0	8.88					
24	....	9.24	10.54	11.22	11.97	12.44
48	....	9.35	10.26	11.76	12.63	13.05
72	....	9.91	10.06	11.36	12.53	13.56
96	....	9.67	10.52	11.91	14.02	

The increase in crude fiber is greatest during the first 24 hours of storage. Increase is much more pronounced at the higher than at the lower temperatures. At the end of 24 hours, the percentage of crude fiber had increased only 4 per cent at 1°C.; while, at 35°C., it had increased 40 per cent.

The degree of lignification at the different temperatures was determined microchemically, counting each day the number of lignified tracheal tubes on the oldest vascular bundles. Lignification takes place the entire length of the spear and at all temperatures, though, in general, it is less at low temperatures than at high and less at the tip than at the butt. In addition to the lignification taking place in the bundles, there is also progressive lignification of the fibers in the pericycle and of the elements immediately surrounding the vascular bundles.

Shipping Seasons and Carlot Movements.—California furnishes the earliest shipments in spring. Most of the carlot shipments of asparagus from California originate in the Imperial Valley and in the Delta region. Asparagus is shipped from the former district until the eastern asparagus

starts to move in considerable quantity, and this may be from the middle to the last of April. Most of the growers in the Delta stop shipping about Apr. 1. A few cars, however, move from the latter district to local markets after that time. South Carolina and adjoining states usually start shipping in March; but most of the asparagus moves from these states in April and May. Illinois and New Jersey start shipping in April and continue through the months of May and June. Table 18 gives the shipping seasons and the number of carloads originating in the various states from 1917 to 1926. There is a considerable amount of asparagus grown in the vicinity of nearly all the large cities, which is hauled to market by truck and therefore does not appear in these carlot totals.

TABLE 18.—SHIPPING SEASONS AND CARLOT SHIPMENTS OF ASPARAGUS, 1917–1926
(*U. S. Dept. Agr., Bureau of Agricultural Economics*)

State	Approximate shipping seasons	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926
California	February to June	265	303	377	502	362	304	458	696	1,279	1,502
Delaware	May to June	4	7	.....	.....	2	.....	5	1	15	
Georgia	March to May	40	.....	.....	.....	.....	.....	.....	8	.....	56
Illinois	April to June	49	23	79	164	159	161	93	157	165	147
New Jersey	April to July	601	674	564	465	237	154	64	156	150	221
Oregon	April to May	1	.....	.....	.....	.....	.....	.....	.....	.....	11
South Carolina	March to May	94	105	81	89	102	143	154	185	263	364
Washington	April to June	3	3	.....	1	2	5	10	10	31	111
Total for United States		1,057	1,120	1,101	1,226	864	767	785	1,223	1,906	2,420

THE ASPARAGUS-CANNING INDUSTRY

Growing asparagus for the canning industry is localized in the Delta region of California. This region seems to be especially well suited for the production of canning asparagus. The soil is light, and the spears grow through 15 to 18 inches of it and remain perfectly straight. Asparagus is cut for the canning factory during the months of April, May, and June. The spears are washed and trimmed in the field, then hauled to the canneries, where they are sorted into a number of grades, then wilted by immersing in hot water, placed in the can, brined, exhausted to remove the air, then capped and processed. Most of the asparagus used for canning is white. It makes a better-appearing product when canned than the green. For a number of years, California has supplied almost the entire domestic demand for canned asparagus besides a large amount for export.

Varieties

The varieties which are now grown most extensively are Palmetto, Argenteuil, Mary Washington, and Martha Washington.

Mary Washington.—The Mary Washington is a comparatively new variety, developed by Norton (1919) and introduced by the United States Department of Agriculture. It is much more uniform in size, shape, and color, and the spears average larger than those of other varieties grown under similar conditions. The spears are green with a purple tinge. The buds and leaf scales remain tight against the shoot for a comparatively long time, making it ideal for the "green-grass" market. The main stem grows very tall and when mature, usually bends over. Mary Washington is claimed by some to be less rust-resistant than Martha Washington. Under California conditions, however, it appears to be as rust-resistant as the latter variety. Both of these varieties seem to be less rust-resistant under California than under eastern conditions.

Martha Washington.—This variety is not especially outstanding in any feature. In some regions where rust epidemics are especially severe, it is claimed to be more resistant than the Mary Washington and for this reason will probably be retained there.

Palmetto and Argenteuil.—Palmetto and Argenteuil appear to be identical. Most of the apparent differences are probably due to soil and climatic conditions and methods of seed selection. Argenteuil and Palmetto are probably the same as the Early Giant Argenteuil grown in the Argenteuil district of France. They are early, prolific, and semi-rust-resistant, and the spears have a purplish overcast.

Breeding

Little improvement can be made by selecting the mature seed-bearing plants only in the commercial fields. By this method, selection is practiced only on the maternal side, whereas both parents should be carefully selected. The selected parents of both sexes that are to be used for breeding had best be planted in beds somewhat removed from commercial plantings. In the breeding, or seed plot, one male to about five or six female plants is sufficient. The plants should be heavy producers throughout the cutting season and over a long period of years. The scale leaves should remain compressed against the stem for a considerable time after coming through the soil. The spear should have a gradual taper from butt to tip and after exposure to light, should be dark green with a purplish overcast. The dark-green varieties seem to be more rust-resistant than the lighter-colored ones, and they also present a better appearance on the market.

Excellent work was done by Norton (1913) in the breeding of rust-resistant varieties. He started by collecting varieties from all over the

world and planting them at Concord, Massachusetts, where they were subject to rust. Of all those collected, not one plant was found to be completely immune, but some were more resistant than others, and these he used for breeding purposes. A male plant, named by Norton, Washington, transmitted its rust-resistant qualities. A female plant, named Martha, selected from the variety Reading Giant, when crossed with the male plant Washington, gave the first progeny lot of Martha Washington. From this cross have come all of our present Martha Washington plantings. A female plant much superior to Martha in many characters was found as a seedling in a bed of Reading Giant in 1910. This plant, named Mary, was also crossed with the male plant Washington, and from this cross have come all of our present extensive plantings of Mary Washington.

Harvesting and Grading Seeds.—When mature, the seed-bearing plants are cut, laid on canvas, and dried. The berries are removed by rolling. The seeds and chaff are then placed in barrels or other containers, water is added, the heavy seeds settle to the bottom, and the light seeds and all other material float off. When washed, the seeds are spread out to dry, then screened and stored. There are approximately 22,000 seeds to the pound.

Diseases

Asparagus Rust (*Puccinia asparagi*).—Asparagus rust is the only disease causing serious injury to the asparagus plant in America. The fungus does not directly injure the young spears which are cut for market. The main damage, caused by the destruction of the chloroplasts that carry on photosynthesis, is due to the reduced supply of reserve food. The lesions appear on all above-ground portions of the mature plant; and when infection is severe, the entire field appears reddish brown.

The rust winters over in the soil or on old asparagus stalks in the resting, or teleutospore, stage. The teleutospores germinate in the spring at about the same time that the asparagus plants start to grow. From each cell of the spore there arises a short-segmented filament bearing four small sporidia, which are distributed by wind and other agencies. Upon the young shoots, the sporidia germinate; and the hyphae grow through the epidermis into the underlying tissue. In less than a month, aggregations of orange-yellow spores, known as "cluster cups," or "aecidia," are produced under the epidermis. The developing aecidiospores finally rupture the epidermis and are liberated. They are disseminated mainly by wind. In the presence of moisture, they germinate on the stems and produce a mycelium, which grows through the stomata into the chlorenchyma. Food is absorbed from the cells of the host plant by the haustoria. This mycelium produces the uredo stage, during which

the greatest amount of damage is done. The uredospores appear 2 or 3 weeks after infection by the aecidiospores. The reddish-brown-spore clusters rupture the epidermis, and the single-celled spores are carried by air currents, gravity, or other means to re-infect other plants or different portions of the same plant. At this stage, especially in regions of excessive summer rainfall or where dews are prevalent, the spread of the rust is very rapid. Under favorable conditions of temperature and moisture, the life cycle from uredospore to uredospore may be completed in less than 12 days. Where dews and rains are prevalent throughout the growing season, the spread of rust from plant to plant and from field to field is very rapid. In the semi-arid regions of the West, especially where the summers are dry, the rust does not spread so rapidly, because moisture is absolutely necessary for the germination of the rust spores.

In the late summer and early fall, the teleutospores arise from the same mycelium as do the uredospores. Most of the teleutospores adhere to the asparagus stalks and probably provide the only means of carrying the disease over winter.

Numerous experiments have shown that in the East spraying or dusting for the control of rust is not practicable. The method now being used is to plant rust-resistant varieties, such as Mary Washington and Martha Washington. Palmetto, Argenteuil, and Reading Giant are not so resistant as the former varieties but are more resistant than the yellowish-green varieties, such as Conover's Colossal.

In California, Smith (1906) found that dusting with S gave good control. The most finely-ground S available should be used, so that it will thoroughly cover and adhere to the plants. Usually from 25 to 30 pounds are required for each application. The number of applications will vary with conditions. Volunteer plants around the edges of the fields should be destroyed. In regions without summer rains or dews, rust seldom appears on the older beds until fall, at which time it usually does little damage. Sulphuring is most generally necessary on the newly established beds, which are subject to infection during the moist days of spring.

Insects

Asparagus Beetle (*Crioceris asparagi*).—The common asparagus beetle is found in most of the asparagus-growing regions of Europe and America. The adult beetle is blue-black in color, with a red thorax and dark-blue wing covers marked with lemon-yellow and with reddish borders, and is slightly less than ¼ inch long. The eggs are deposited upon the aerial stems, usually in rows of two to seven. The mature larva is about ⅓ inch long, soft, fleshy, much wrinkled, and of a dark-gray or olive color, with shining black head and legs. The larva pupates just

below the soil surface in an earth-covered cocoon. In its northern range, usually two generations are produced in a season; while in the South, there may be as many as four broods. Both adults and larvae feed upon the spears and mature stalks.

The beetles are held in check by natural enemies, such as ladybird beetles which feed upon the eggs, soldier bugs and dragon flies which prey upon the larvae, and an egg parasite (*Tetrastiches asparagi*). In Concord, Massachusetts, Chittenden (1917) observed that large numbers of hibernating beetles are killed during the winter, when very low temperatures follow a period of warm weather.

The following methods of control have been recommended: (1) Flood during the winter; (2) cut white asparagus, so that beetles will not have a place to lay their eggs in the spring; (3) allow chickens and ducks to forage in the fields; (4) to kill the larvae, dust the plants with air-slaked lime when they are wet with dew; and (5) use trap hills during the cutting season, keeping these sprayed with arsenicals. After the cutting season, the best method of control is to spray or dust the plants with arsenicals.

The 12-spotted asparagus beetle (*Crioceris duodecim-punctata*) is distinguished from the common asparagus beetle by its broader wing covers, each of which is orange-red with six black spots. The eggs are deposited on mature stalks toward the ends of the shoots and singly, on their sides. The larvae feed within the berries. Pupatation takes place in the soil. In the latitude of Ithaca, New York, there are two generations each year. Control of the adult is similar to that for the common asparagus beetle. Since the larvae feed within the berry, it is difficult to control, and the dusting or spraying with arsenicals must be thorough.

Asparagus Miner (*Agromyza simplex*).—The asparagus miner is widely distributed. The adult is a metallic black fly about $\frac{1}{6}$ inch long. Eggs are laid at the base of the asparagus stalk, just below the epidermis. The larvae injure the stalk by mining at the base of it, under the epidermis. Fink (1913) recommends the addition of syrup as an attractant to an arsenical spray which is used to kill the adults. He also recommends pulling and destroying the infested stalks, which generally turn yellow or die before the non-infested do.

Garden Centipede (*Scutigerella immaculata*).—The garden centipede is an economic pest of wide distribution. It has not been reported as attacking asparagus except in the Delta region of California. The adult is small and, when feeding on asparagus, is almost transparent in color. The centipede eats small holes in the asparagus spears below the soil, making the spears undesirable for canning purposes. According to Wymore (1924), the best method of control is some time during the winter to cover the land with about a foot of water for 2 or 3 weeks.

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PART III

POLYGONACEAE

Garden rhubarb (*Rheum rhaponticum*) is the only member of this family cultivated as a vegetable, though the wild docks and sorrels, which belong to the genus *Rumex*, are sometimes used as greens.

CHAPTER IV

RHEUM

The fleshy roots of the rhubarb plant have for ages been used medicinally by the Chinese and Russian peoples. Use of the petioles as a vegetable is comparatively recent. Rhubarb is now one of the most popular early-spring vegetables. Extensive plantations have been developed in New Jersey and other northern states, but the bulk of commercial production is in California. The most important district is in Alameda county, whence carlot shipments are made to eastern markets during February and March. A second district is near Los Angeles, whence it is shipped throughout the year. There is little demand for this vegetable except in early spring, however, and the best prices are received at that season.

Taxonomy.—A dozen or more species have been ascribed to the genus *Rheum*, several of which have probably furnished cultivated varieties. Linnaeus considered the cultivated rhubarb of Europe to be *R. rhaponticum*, which is the commonest species. Later, he changed it to *R. palmatum*, and the investigations of Colonel Prjewalsky (cited by Williams, 1891) indicate that this species, found by him in the Tsinghai province of Mongolia, is the source of the finest Chinese rhubarbs. Other species, mentioned by Sturtevant (1919) are *R. compactum* L., a native of Tartary; *R. emodi* Wall., red-veined rhubarb, from the Himalayas; *R. hybridum* Murr., from Mongolia, said to have the largest plants, including the Victoria variety; *R. nobile* Hook. and Thomp.; Sikkim rhubarb, an ornamental variety; *R. ribes* L., the currant-fruited rhubarb of Syria and Persia; and *R. undulatum* L. With reference to *R. emodi*, the plants are said to have long stalks of finest quality, but Burr (1863) says that they are unfit for use because of their excessive purgative qualities.

The multiplicity of species is in part due to the fact that systematists have depended largely on the branching of the inflorescence and the contour of the leaves, characters which Williams shows are not constant.

History.—Rhubarb is native to the cold regions of Central Asia. It was introduced to Europe in 1608, probably from China, and was first grown in Italy. Seeds were taken to England about 1640, and the known variability of plants grown from seeds may account for the diversity of forms developed there. According to Sturtevant, the first mention of its use as a vegetable was in 1778. It was in common use in America in 1806.

Plant Characteristics

Rhubarb is a herbaceous perennial. The underground portion consists of large, rather woody rhizomes and a fibrous root system. Near the surface of the soil is the "crown," a stem much compressed vertically. Early in spring, several large rosette leaves arise from the crown; and the long, thick petioles of these are the edible portion of the plant. Later, the stem elongates to a height of 3 to 5 feet and bears several elongated, leafy inflorescences.

The petioles of both rosette and cauline leaves are enclosed at their base in a membraneous sheath, the ocrea. The petioles vary considerably in size and may be cylindrical, semi-circular, bi-laterally compressed, or polygonal, in the various varieties. The petioles may be smooth or

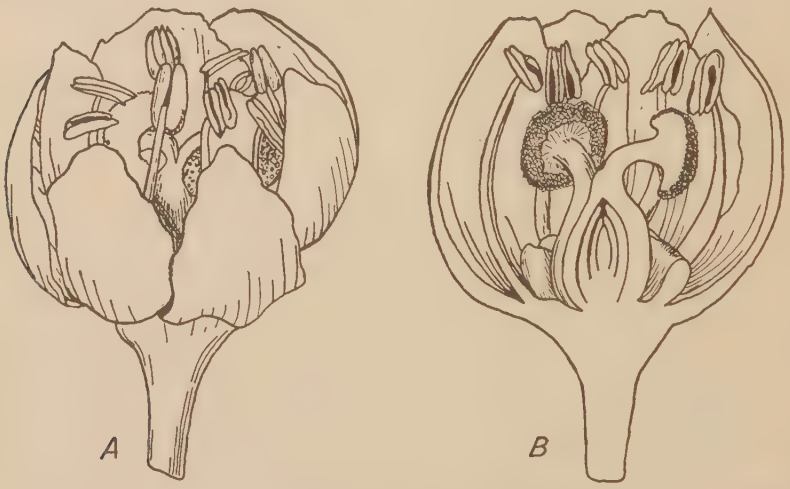

Fig. 19.—A. Rhubarb flower in anthesis. B. Portion of perianth removed. (*Redrawn from Robbins, Botany of Crop Plants.*)

furrowed on either or both surfaces. The leaf-blade is large and spreading, more or less circular, and cordate at the base, entire, or with undulate-crenate margins, or divided into lacinated lobes (in *R. palmatum*).

The inflorescence is paniculate, with raceme-like branches. The degree of branching of the inflorescence varies in different varieties. From the axils of the first and second leaves on the stem, there are seldom any inflorescences; but in each of the axils of the upper leaves, three peduncles arise, the central one becoming most strongly developed. The branches of these peduncles terminate in racemes, which produce alternate fasicles of flowers along the rachis.

The small, white flowers are borne on short-jointed pedicels. The floral envelope consists of a six-lobed calyx, or perianth, without a corolla; it dries up after maturation but remains attached to the base of the fruit.

An outer whorl of six stamens and an inner whorl of three arise at the base of the ovary. In some species, as *R. nobile*, the inner whorl is suppressed. The stigma is three-lobed; it is not receptive until after the anthers have shed their pollen. The flattened fruit, containing a single seed, is a samaroid achene, by some authors called a "caryopis," by Bentham and Hooker a "nut" and by Meisner, an "achene." The seed is enclosed in the pericarp—a persistent, thin, sub-cutineous covering, which is somewhat extended laterally to form wings.

Because of the prevailing protandry, self-pollination within the individual flowers cannot occur, but pollen may fall from the upper flowers, which open later, to the stigmas of the lower ones. Unsuccessful efforts to obtain seed from single isolated plants indicate that some plants at least are self-sterile. Protandry and self-sterility favor cross-pollination, and the variable plants produced by seed indicate hybrid ancestry. The physiological conditions leading to flower-stem formation are not well understood. Some varieties have a greater tendency to stem elongation than others. Unfavorable growing conditions, such as infertile or poorly cultivated soils and abnormally low temperatures early in the growing season, seem to cause more abundant and earlier stem formation. Presumably, the flower stems should be removed as soon as they appear, to avoid the utilization of food materials in stalk and seed formation.

Climatic and Soil Requirements

The rhizomes and crown of rhubarb are very resistant to cold and to desiccation. When dormant, they may remain in soil frozen all winter, or in dry soil throughout a hot, rainless summer, without injury. Hence, this plant is well suited to culture both in very cold countries and in warm, dry ones. Outside of California, however, rhubarb culture in the United States is limited to regions north of the Potomac and Ohio rivers. Apparently, the plants are not able to stand the hot, humid summer of the South. In the North, the crowns are dormant during the winter; in California, they are dormant during the dry summer. A dormant period is not absolutely necessary, however, for in southern California, some plantations are kept growing and producing throughout the year, under irrigation.

Leaf growth from the crowns begins soon after the ground thaws in spring and proceeds rapidly at low temperatures. Thus, rhubarb is ready for harvesting quite early in spring. The vegetative parts of the plant are not very resistant to cold, however; temperatures of -3 to -4°C. will freeze the petioles and ruin the crop for two to three pickings. Low temperatures are essential for the development of the pink pigment so much desired in the petioles. Under high temperature conditions, the petioles of all varieties are greenish.

Rhubarb is grown successfully on fertile, sandy-loam soils. Most of the rhubarb in California is grown on heavy, silt-loam soils, without irrigation. Good drainage of such soils is essential for early production. On sandy or gravelly soils deficient in N, some growers make a practice of applying 250 pounds per acre of sulphate of ammonia as a side dressing after each picking. Heavy applications of stable manure are generally made to rhubarb plantations each year. Abundant supplies of moisture and nutrients are required for the rapid growth of the vegetative parts.

Culture

Propagation.—Division of old plants is the usual method of propagation. Vegetative buds are formed on the upper portion of the thick, fleshy rhizomes. By cutting up an old plant, several pieces of rhizome with well-developed buds are secured. Pieces of rhizome without buds are not likely to produce plants. Division should be made while the plants are dormant, in late fall or in winter. Spring propagation and planting is extensively practiced but is not desirable unless the crowns can be dug and divided before growth commences. In southern California, propagation is often done at the end of the picking season, in May, and fair growth is obtained, if the plants are irrigated during the summer.

Handling the Plantation.—In the North, picking begins in April, with the development of the first leaves, and continues to June, though some growers continue pickings throughout the summer. In the fall, old leaves and stalks are disked into the soil, and a winter mulch of stable manure is applied. In Alameda county, California, the rows of plants are bedded with soil as soon as growth commences in February. This forces the leaves to grow through a considerable mass of soil and results in longer stalks, with a delicate pink color. There seems to be no reason to believe that the length of picking season affects production the following year, if only fully developed leaves are picked. California growers stop picking when the flower stalks appear, after which the tops soon die. The roots remain dormant until the advent of winter rains.

The plants produce a small crop the second year after setting. Maximum production is obtained from the third to the seventh year. By the tenth year, each plant has multiplied to such an extent that severe crowding results, and the petioles become spindling. The crowns are then plowed out, and a new plantation established. In California, some plantations of the Strawberry variety, 15 to 20 years old, are still producing profitably.

Forcing.—To meet the demand for rhubarb during the winter, forcing is practiced in the North. The roots are dug before the soil freezes in autumn and set in forcing cellars, hotbeds, or special forcing houses. In order to hasten the growth of the buds, which are in a dormant condition at this time, the roots are usually allowed to freeze several times

before forcing commences. Sayre (1924) found that a temperature of −6.6°C. was effective in starting rapid growth, while −12°C. was injurious. Card (1899) also reports that frozen crowns grow more rapidly than those not frozen before forcing. Desiccation and exposure to fumes of ether overnight in a closed container also have a marked stimulating effect. Light is not desired in the forcing of rhubarb. In darkness, the leaf blade is reduced in size, petiole elongation is more rapid, the color produced is a more delicate pink, and the flavor is less acid than when the plant grown in light. Card observed that a much greater absolute weight of petioles was produced in the dark. Sayre (1924) found about 15°C. to be the optimum temperature for large yields and good color; at higher temperatures, the pink color tended to disappear. Watering increased the yield markedly and did not lessen the color. Four-year-old plants produced more and larger petioles than those one year old, but the latter gave the greater net profit.

Marketing

The petioles are washed and the leaf blade is trimmed off, in preparing rhubarb for market. For local markets, rhubarb is usually bunched, but for shipment, the petioles are packed in bulk, usually in standard apple boxes. During February and March, before the eastern crop is available, rhubarb is extensively shipped under refrigeration, from California to eastern markets. Some shipments are also made during the winter, but the demand is not large. The cost of picking and packing ranges from 30 to 40 cents per box.

The petioles are sorted into three grades, known as "fancy," "extra choice," and "choice." The grades depend largely on diameter of the petiole, as measured one-third the distance from the base. The fancy grade is ⅞ inch or more in width; extra choice ½ to ⅞ inch; and choice, ⅜ to ⅝ inch. Color is also considered in grading.

Varieties

Only two varieties, Victoria and Linnaeus, are grown in the East, while several other varieties, mostly of recent origin, are grown in California.

Linnaeus.—The petioles are pink, small, and very numerous. This is probably the same variety as "Strawberry" which is so extensively grown in Alameda county, California. It is the most popular variety on the markets, because of its tenderness and high color.

Victoria.—The plants are larger and stockier and the petiole thicker and more inclined to be green than in the Linnæus variety.

Giant Crimson Winter.—This variety is somewhat like Victoria. It is supposed to be one of Burbank's introductions. It is grown to some

extent in the interior valleys of northern California and was formerly shipped during the winter from southern California. The large, greenish stalks are characterized by a speckled-pink color.

Giant Cherry.—This variety was selected about 1918 by W. J. Embree, El Monte, California, from a large number of seedlings. The petioles are very large and thick. Under favorable conditions, they become 4 feet long, over 1 inch wide, and a deep, cherry red for their entire length. They can be cooked without peeling, thus giving maximum color to the cooked product.

Panama and **Senator** are varieties of the same general type as Giant Cherry and were introduced about 1915, by J. B. Wagner, Pasadena, California. They were selected from seedlings of presumably hybrid origin. These varieties are more productive than the Strawberry, but it remains to be seen whether the markets will like them as well. Brandywine and Amber are other varieties.

Breeding

The growers have been instrumental in the development of improved varieties. Possibilities for improvement are indicated by the work of Myers (1922): He grew 1,143 seedlings from nine different lots of rhubarb. Only 11 plants seemed superior, and, after division and further propagation, only five seemed distinctly superior to varieties in cultivation.

Diseases

Crown Rot (*Phytophthora cactorium*).—Dying of isolated plants during the summer was observed in Pennsylvania in 1915. The cause of the trouble was found by Beach (1922) to be a soft rot of the crown and basal portion of the petiole. The leaf-blade wilts and dies slowly. Much of the loss previously attributed to the anthracnose disease seems traceable to this crown rot (the anthracnose fungus being a weak parasite, generally invading leaves already weakened by other causes). Infection is said to result from the division of partly diseased crowns; also, the organism enters from the soil through wounds made in preparing the cuttings. The disease is prevented by using propagating material from non-infected fields and by planting on non-infected soil. Disinfection of the cuttings before planting is also recommended by Beach as a precaution, where infection is suspected. If the buds are dormant, the cuttings may be safely soaked in mercuric chloride 1:1,000, for ½ hour.

A very similar disease, foot rot, was found by Godfrey (1923) to be caused by a closely related fungus, *Phytophthora parasitica*, var. *rhei*, and is widely distributed.

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PART IV

CHENOPODIACEAE

The family contains a large number of genera and species noted for their halophytic nature. It is indigenous to seashores and saline places. Its members cultivated as vegetable crops are *Beta vulgaris* (beet), *Beta vulgaris* var. *cicla* (chard) and *Spinacea oleracea* (spinach).

CHAPTER V

BETA

SECTION A. GARDEN BEET

The beet is a herbaceous biennial. During the first year, it produces a rosette of leaves and stores food in the fleshy tap-root. In the second year, it develops flowers, fruit, and seed. The garden beet is grown extensively, though in small acreages, in all parts of the United States. In the South, it is grown in considerable quantity and shipped with other vegetables in mixed cars. The tops are sometimes used as greens, while the root is used mainly for pickling. The canning of beets is also becoming an important industry in the North and in the Pacific coast states. Sugar beets, and stock beets or mangels, are two other groups of considerable importance though not used as vegetables.

History.—The beet is thought to be a native of Europe and North Africa. It is probably a modern vegetable; the first mention of its use as a food is in the third century. Its first appearance as the improved beet is recorded in Germany, about 1558, and in England, about 1576. The greatest improvement in the sugar beet was effected by the German and French workers, and the American seedsmen have done much to improve the varieties of table beets. Goff (1887) described 23 varieties of garden beets, excluding synonyms.

Plant Characteristics

Roots.—The fleshy part of the beet is composed morphologically of three regions—the crown, the neck, and the root. The crown bears a tuft of large, succulent leaves. As the lower leaves mature, they are abscissed, leaving a scar on the side of the crown. The portion of the beet developed from the hypocotyl is known as the "neck." The portion below the neck develops from the tap-root, and two opposite rows of secondary roots arise from it. The tap-root extends almost straight downward, and the lower portion becomes very small. From the central tap-root branches spread outward and downward. The upper main branches are the largest and extend outward almost horizontally for more than 2 feet. The lower laterals incline more and more and finally run nearly parallel to the tap-root. Weaver (1925) states that the root system of the sugar beet grows down to a depth of 5 or 6 feet but that the habit of growth varies considerably under different soil conditions. Where the sub-soil is

moist, the penetration of the tap-root is deeper than when it is dry. Root stratification is also common, the lateral roots occurring in greatest profusion in the heavier layers where moisture and nutrients are more abundant.

A median cross-section through a mature beet shows a number of growth rings. Each ring is made up of a narrow band of vascular tissue and a broad band of storage parenchyma. In the narrow, tapering zone of the tap-root, the number of annular rings decreases as they gradually unite with one another. The rings also merge in the crown.

In the young seedling, there are three distinct regions—root, hypocotyl, and cotyledons. The junction between hypocotyl and root is indicated by the appearance of lateral roots. The primary growth of the seedling is concluded with the appearance of the first pair of true leaves. This may take from 8 to 20 days after the seed is planted, depending upon the temperature. When the first pair of true leaves appear, the beet has a diameter of only a few millimeters, while that of the mature beet is 15 centimeters or more. This increase in thickness is the result of cambial growth accompanied by cell division and cell enlargement of the parenchyma. There are two distinct phases of cambial activity—differentiation and growth of the primary cambium and development of secondary cambiums. The primary cambium forms the innermost annular zone, while the secondary cambiums form a large number of additional rings, of which only the inner five or six mature their tissues.

According to Artschwager (1926), when the seedling is about 10 days old and the second pair of leaves appear, the parenchyma cells between the primary xylem and primary phloem become meristematic, forming the primary cambium, which develops secondary xylem and secondary phloem. The primary cambium continues to grow for a time, but soon the secondary cambiums begin to function. In the young seedling, the first phloem cells develop adjacent to the pericycle, and the metaphloem, which develops later, is separated from the pericycle by a single layer of procambial cells. The cells of this layer enlarge and then divide, thereby placing an ever-widening band of parenchyma between pericycle and phloem. The band of parenchyma is not of uniform width, partly because cell division in the primary phloem parenchyma causes certain of the phloem groups to remain near the pericycle. Soon, periclinal divisions in certain cells of this band initiate the secondary cambium. This method of development is characteristic for the root and lower hypocotyl. In the upper hypocotyl, however, the cambium arises entirely in the pericycle. The central hypocotyl shows transition stages, and more and more pericycle cells take part in cambium formation as the apical region is approached.

The cambium, when once formed, produces a ring of bundles and parenchyma tissue. Since additional cambiums are formed, however,

the behavior of the first cambium initial differs from the normal behavior of cambium cells. When the cambium initial undergoes the first division, the outer of the two daughter cells becomes the initial of a new secondary cambium, while the inner daughter cell divides further and produces xylem, phloem, and medullary-ray tissue. This process is repeated until, all secondary cambiums have been formed. There is, however, no uniform method governing the formation of the secondary cambiums. Since most of the secondary cambiums are initiated in quick succession, a root no thicker than a pencil contains almost all the zones or rings developing simultaneously.

The periderm of the beet develops from the pericycle. Its formation is initiated when the seedling has about 5 pairs of leaves, at a time when the secondary cambiums are forming and the primary cortex is being sloughed off. This process takes place first in the root zone and extends gradually into the hypocotyl. When periderm development begins, tangential division in the cells of the pericycle converts it into a band of meristematic tissue, known as the phellogen, or cork cambiums. From the phellogen are formed cork cells on the outside and phelloderm cells on the inside. The number of phelloderm cells, however, is smaller than the number of cork cells, since the latter are constantly being sloughed off and must be replaced. The periderm forms a thin covering, from five to eight cells thick. The walls of the periderm cells are thin and suberized, except for the middle lamella, which is lignified.

The peculiar zonation noticed in a cross-section of beet root is produced by concentric rings of vascular tissue enclosing broad bands of parenchyma. Near the periphery, the rings are very narrow because the tissues are just in the process of differentiation.

Leaves.—The leaves are arranged on the crown in a close spiral, with the oldest leaves on the outside. They may vary in color from dark red to light green. The petioles of the leaf may be long or short; the blade, oblong or triangular, with a straight or wavy margin and a smooth or crinkly surface. The great variation existing in leaf type within a single variety is probably due to a heterozygous condition for the various leaf factors. Artschwager (1926) found the number of stomates on the upper surface to vary from 57 to 138 per square millimeter and on the lower surface, from 59 to 167.

Flowers and Inflorescences.—The flowering stems usually arise from the crown the second year. When planted out the second season, according to Artschwager (1927), the mother beets first produce a rosette of leaves like those of the first year; but later, the newly formed leaves become progressively smaller; and finally, the apical portion begins to elongate, thus initiating the development of the floral axis. The floral axis grows very rapidly. The mature inflorescence is composed of large paniculate, more or less open, spikes. Artschwager states that

. . . rudiments of the young flowers appear close behind the growing point of branches of the inflorescence axis. Each rudiment is borne in the axil of a large bract and is accompanied by two lateral bracts each of which has in its axil a flower. The flower primordium forms a small protuberance on which are soon differentiated five narrow ridges, the beginnings of the sepals. Next there appears within this circle a whorl of papillae, the stamen rudiments each opposite a calyx lobe.

Finally, three more ridges—the carpels—develop at first separately but later join to form the cavity of the ovary, in which a single ovule develops. The latter arises near the base of the carpels. The young ovule is straight, but with the growth of the integuments it becomes campylotropous.

The flowers are sessile and occur singly or in clusters of two or three attached to the inflorescence axis or secondary branches of the latter in the axils of the bracts. They are small, greenish, and perfect. The calyx is five-parted and incurved, adhering to the base of the ovary and becoming hard in the fruit. There are five stamens inserted at the base of the calyx lobes. The stamens face inward, are

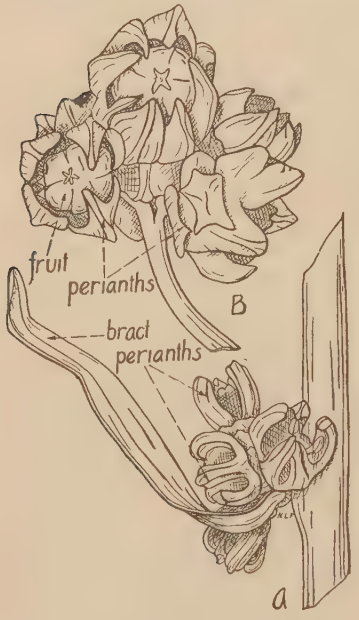

Fig. 20.—Flowers of beet. A. Flowers grouped in the axil of a bract. B. Cluster of flowers which fuse to form a seed ball. (*Robbins Botany of Crop Plants.*) (*Courtesy P. Blakiston's Son & Co.*)

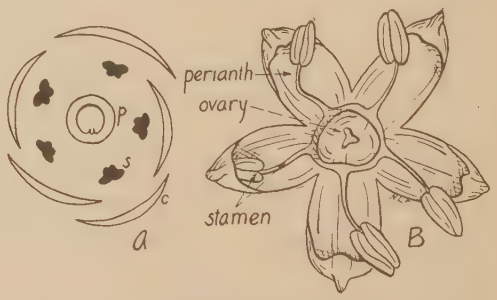

Fig. 21.—A. Floral diagram of beet. B. Flower, face view. (*A. after Bessey.*) (*From Robbins, Botany of Crop Plants.*) (*Courtesy P. Blakiston's Son & Co.*)

bilocular, and dehisc longitudinally. The three-carpellate ovary is sunk in a fleshy disk, which encloses a single ovule. The style is very short and terminates in a three-lobed stigma which persists in the fruit.

Pollination.—According to Artschwager (1927), the beet flower opens in the morning, and the sepals expand, leaving the stamens exposed and in an upright position. If the day is warm and bright, the anthers dehisc in the forenoon. The beet flower is protandrous and is chiefly wind-pollinated. A large amount of pollen is produced, and this can be carried

for long distances. Insects play only a minor part in pollination. Shaw (1914) states that thrips carry pollen from plant to plant and that they assist in the pollination of beet flowers probably to a greater extent than does any other species of insect. Artschwager (1927) states that

> . . . at the time of the opening of the flower, the stigmatic lobes are still closed. They begin to open very gradually in the afternoon but may not fully expand until the next day or the following one. One frequently observes flowers with anthers already shrivelled but completely closed stigmatic lobes; on the other hand, the shedding of the pollen and the opening of the stigma lobes may occur simultaneously, though such cases are very rare.

Fertilization and Seed Development.—According to Artschwager (1927), the embryo sac contains, at time of fertilization, the egg and the fused polars. Fertilization takes place a day or so after the pollen is shed. After the embryo has grown to the four- or six-celled stage, the primary endosperm nucleus begins to divide, and the nuclei migrate toward the periphery, where they become embedded in the cytoplasm and continue to divide. After a period of free nuclear division, the endosperm nuclei become invested by walls, and gradually the entire cavity of the embryo sac is filled with endosperm, which, however, is again dissolved and absorbed by the growing embryo, with the exception of a single layer of cells surrounding the radicle.

Fruit and Seed.—A multiple fruit is formed by the cohesion of two or more flowers grown together at their bases and forming a hard, irregular, dry body, the so-called "seed ball." If the flower stands alone in the axil, a "single germ" seed will develop. The mature seed is a shining, lentil-like structure, about 3 millimeters long and 1.5 millimeters thick. The embryo occupies a horizontal position and is curved in such a manner that it completely encloses the perisperm. The cells of the outer integument contain starch, and there is an extensive tannin deposit in both integumentary layers. The reddish-brown color of the mature outer seed coat is due to the pigmentation of the outer layer.

Climatic and Soil Relationships

The garden beet usually attains its best color, texture, and quality if grown during the cool season. Kotowski (1926) found that beet seeds of the Crosby's Egyptian variety germinated well at temperatures ranging from 8 to 30°C. Of the temperatures used, the best germination was obtained at 11°C. As shown in Table 19, no seedlings appeared above ground at 4°C. When seeds held at this temperature for 60 days were transferred to 30°C., however, good germination was obtained. At 4°C., there is some growth of the radicle, but growth of the hypocotyl seems to be inhibited.

TABLE 19.—GERMINATION OF BEET SEED AT DIFFERENT TEMPERATURES
(*Kotowski*, 1926)

Temperature °C	4	8	11	18	25	30
First seedling, days after sowing	0	20	12	6	4	3
Last seedling, days after sowing	0	42	24	15	12	12
Seedlings in per cent of seed sown	0	110	131	120	122	101

Beets are usually grown on sandy-loam or muck soils. When a symmetrical root is desired, as for canning, a very loose soil is the best type to use. The beet is intolerant of acid soils but thrives well on soils that are somewhat alkaline or saline.

CULTURE

The seed is usually sown in rows 12 to 15 inches apart at the rate of 4 to 6 pounds per acre. When about 2 inches high, the plants are sometimes thinned to 3 or 4 inches apart in the row. It is impossible to regulate planting so as to have just one plant in a place, because the seed ball usually contains two or three seeds. When the beets are pulled small for pickles or greens, the first harvest may take the place of a thinning. When the beets are to be bunched, they are pulled when about 1½ to 2 inches in diameter. The late crop of beets is usually topped in the field, then sold immediately or placed in storage.

MARKETING

Grading.—The specifications for the different grades of bunched beets have been outlined by the Bureau of Agricultural Economics. For U. S. Grade No. 1, it is required that the beets be of similar varietal characteristics—firm, well formed, smooth, clean, and free from decay and from damage caused by disease, insects, or mechanical or other means. The tops shall be fresh and clean and either full size or cut back to not less than 6 inches in length. Not more than 5 per cent, by count, may be below the requirements of the grade, but no part of this tolerance is allowed for decay. For U. S. Grade No. 2, it is required that the beets be free from decay and excessive dirt and from serious damage caused by disease, insects, or mechanical or other means. The tops must also be free from serious damage from any cause. The same tolerance is allowed as for U. S. Grade No. 1. U. S. Grade No. 3 consists of beets which do not meet the requirements of the foregoing grades. The size of the beets may be stated in terms of minimum diameter, or the beets may be classified according to their diameter at the crown as "small" (1½ to 2 inches), "medium" (2 to 3 inches), and "large" (over 3 inches). Unless otherwise specified, the minimum size shall be 1½ inches. Not more than 5 per cent by count may be below the specified minimum size. It is also required that the bunches be fairly uniform in size.

Shipping Seasons.—Most of the bunched beets are shipped in mixed cars during winter and spring from the South and from California. A few straight cars are shipped to the large consuming centers. The beets are packed in various types of containers. Late beets are grown in the North; the crop is harvested in September and October and shipped immediately or stored. Beets are stored in outdoor pits or vegetable cellars. The temperature should be kept just above freezing. The relative humidity should be kept high to prevent withering of the roots.

Classification and Varieties

Goff (1887) divides the garden beet into four classes, according to root shape, as follows:

Root oblate or top-shaped
- Root red. (Bassano, Eclipse, Early Flat Egyptian)
- Root yellow (Yellow Turnip)

Root oval
- Root red (Detroit Dark Red)
- Root yellow (Golden Tankard)

Root half-long
- Root red (Half Long Blood)
- Root yellow (Yellow Castlenaudary)

Root conical
- Root red (Long Blood)
- Root yellow (Long Yellow)
- Root black or blackish (Black Skinned)

The red-rooted varieties are the only ones which are now grown to any extent. The most popular early variety is Crosby's Egyptian. The Detroit Dark Red is the most popular variety for the late crop.

Crosby's Egyptian.—This variety was developed by Josiah Crosby, a New England market gardener. It grows very rapidly; the tops are small; the root is slightly thicker than the Early Flat Egyptian but not as thick as Detroit Dark Red. The flesh is a blood-red color; and in the best strains, there is very little light zoning.

Detroit Dark Red.—This variety was introduced in 1892 by D. M. Ferry & Co. of Detroit, Michigan. Besides being the most popular variety for late planting, it is used more than any other variety for canning purposes. The root is globe shaped; the flesh is dark red and is zoned with a lighter shade of red.

Breeding

Probably the best method to use in the improvement of garden beets is to plant the selected mother beets under isolated conditions, where they will self-pollinate without covering. Many efforts have been made to enclose mother beets in cloth cages or paper bags, but the results are usu-

ally not satisfactory. The best roots are selected from the commercial stocks; the flesh color is usually determined by cutting a V out of the beet root or by obtaining a core from the root just below the crown, by means of a punch. The individual beets are then planted where they can be left uncovered during the blooming period without danger of cross-pollination with other plants. Usually, a fair set of seed is obtained, The beet plant is very heterozygous, and the first inbred generation is usually a very heterogeneous lot. Desirable individuals are again selected and may be inbred again or grouped to get a good set of seed. As far as is known, experiments have not been conducted to determine the influence upon vigor of continuous inbreeding.

Seed Production

Much of the beet seed used in the United States is imported from Europe, but there is some grown in the United States in the West and in the North. In the North, and where the winters are cold, the general custom is to grow mother beets as a fall crop; they are held in storage over winter and planted in the field the following spring. In California, seed for the mother beets or stecklings is usually sown in August; the beets are then pulled during November and December, the tops are removed, and the roots are transplanted in checks about 3 feet each way. The plants bloom in July, and the seed is usually ripe in September.

Insects

Leafhopper (*Eutettix tenella*).—The beet leafhopper is confined to the western United States, being prevalent in the Rocky Mountain region and the Pacific coast states. According to Essig (1926), the species normally breeds in the foothills near arid or desert regions, on filaree, atriplex, and other plants, and migrates or disperses to the valleys in April, May, or June, depending upon the region. There are a large number of food plants chief of which are filaree, atriplex, beet, Russian thistle, sea blite, sarcobatus, creosote bush, mesquite, wild gourd, pepper grass, malva, poverty weed, sea purslane and lamb's quarters.

The nymph or adult leafhopper, in feeding upon the beet, produces a disease known as "curly leaf" or "curly top." Only individuals which have first fed on diseased plants, including both wild and cultivated forms (beet; field, garden, and lima beans; cucumber; mustard; peppers; radish; spinach; squash; and many other native and cultivated plants) can transmit the disease to healthy plants. The true nature of the disease is unknown. It causes damage estimated in millions of dollars annually to the sugar-beet industry of the western states. The disease affects garden, stock and sugar beets, and chard. Severity of the disease is largely condi-

tional upon the number of insects present and upon the size of the beets. If the insects attack the beet plants when the latter are small, the results are usually disastrous. When large, the plants are apparently better able to resist the attack.

An inoculation period of 7 to 14 days after infection is required for the appearance of the disease on beets. An early symptom is the transparent venation of the younger leaves. There is then a thickening of all the smaller veinlets of the leaf, giving it a roughened appearance on the under side. There is at first no change in leaves which are mature at time of infection; later, however, they turn yellow and die. The conspicuous vein swellings and leaf curlings occur only in the young leaves and new growth. The thickening of the small veinlets is followed by a curling of the edge and a final rolling up of the leaf, the upper surface always being rolled in. The vein swelling in some plants becomes very conspicuous. Infected plants also produce a large number of fibrous secondary roots. The phloem may be necrotic, extending throughout the vascular system, and in extreme cases, shows as dark rings in cross-section of the root. Young plants may be killed by early severe infestation, while in the older plants, dwarfing is characteristic.

The most promising method of control is the selection of resistant strains. That some strains are much more resistant than others has been demonstrated by Carsner (1926) and in the unpublished work of others. The loss from curly top can be overcome to a considerable degree by early planting so that the plants will be well established before the attack of the leafhoppers. Satisfactory methods of control by dusting or spraying have not been developed.

SECTION B. CHARD

According to Sturtevant, chard was the *beta* of ancient times and of the Middle Ages. Aristotle noted red chard in 350 B.C. Chard is mentioned by Columella and other Roman writers. It is mentioned as early as the seventh century in Chinese writings.

The climatic and soil requirements are about the same as for the beet. Chard is grown for the large leaf-blades, which are used as greens and for the fleshy petiole and midrib, which are often cooked and served like asparagus. Seed is usually sown in the field in early spring in rows 2 feet or more apart; when established the plants are thinned to about 12 inches apart. They produce greens throughout the season. As the older leaves are pulled from the ou side, new ones develop from the center. Chard is chiefly a home-garden crop, grown to a limited extent only by the market gardeners; it grows to a height of about 2 feet and has yellowish-green, crumpled, and savoyed leaves. It is subject to attack by the same insects and diseases as is the beet, and the methods of seed production and handling are the same.

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CHAPTER VI

SPINACIA

Although spinach probably has been in cultivation for 2,000 years, it did not attain commercial importance until recently. Modern knowledge of nutrition has indicated the especial value of this plant's succulent leaves as food, because of their richness in vitamines and ash constituents. Spinach is widely cultivated as a market-garden crop in the North, for winter shipment in the South, and for canning in the Pacific coast states.

Taxonomy.—The early botanists divided *Spinacia* into two species, *S. spinosa* Moench. and *S. inermis* Moench., these forms having spiny and smooth seed, respectively. Linnaeus (1757) combined them into one species, *S. oleracea L.*, with two varieties: *A*, spiny-seeded, and *B*, smooth-seeded. Vilmorin, in 1883, described three forms, *S. tetandra*, *S. spinosa*, or "English spinach," and *S. oleracea*, or "round-seeded spinach." The first of these was hardly distinguishable from *S. oleracea*, because the number of stamens is not constant. Nohara (1923) found that spiny and smooth-seeded varieties crossed readily, being separated only by a single factor difference for development or non-development of spines, the former being dominant. Nohara considers the two forms merely as varieties of the same species, and, since the spiny-seeded form appears to be the older, it is probably the species type, the smooth-seeded form having arisen from it by gene-mutation. The name "spinach" was probably suggested by the spiny seeds.

History.—Spinach was not known to the ancient Greeks or Romans. According to Sturtevant (1919), it was first cultivated by the Arabs, by whom it was introduced into North Africa and thence taken to Spain by the Moors. De Candolle (1863) thinks that spinach was cultivated in Persia about 2,000 years ago. During the Middle Ages, it gradually spread from Spain to other western European countries. It was grown in the monastic gardens of that period and eaten by the monks on fast days. According to McMahon, it was commonly cultivated in the United States in 1806. In 1828, the savoy-leafed variety was introduced by David Landreth and soon became the leading one. The development of the canning industry, since 1915, has revived the demand for larger-growing, smooth-leafed varieties.

Plant Characteristics

Roots.—The root system consists of a thickened tap-root, extending 2 or 3 feet into the soil, usually without large laterals, the fibrous feeding roots being borne directly on the tap-root.

Leaves.—The leaves of the primitive forms of spinach were probably very long, narrow, and arrow-shaped, with a smooth surface. Under cultivation, however, several distinct varietal forms have developed. The leaves may be more or less sagitate, as in the poorer strains of the Prickly variety; hastate, as in the Thick Leaf type; or rounded. The surface may be smooth, slightly undulating, or savoyed. The latter condition is often referred to as "blistered," or "crumpled," and it is due to the continued growth of the parenchyma between the veins of the leaf.

Stems.—Spinach is an annual, though there are two distinct stages in the life history of the plant—crown development and flower-stalk formation. Following germination, a crown is formed near the surface of the ground. This is really a longitudinally compressed stem, from which a number of leaves arise in nearly the same plane. These rosette-leaves are the edible part of the plant; their number and size are influenced by many environmental factors, especially by the amount of space the plant has for its development. After the development of the crown and rosette of leaves, the stem elongates and branches, forming the flower-stalks. These bear the "cauline" leaves and the axillary clusters of flowers. The development of the flower stalks is referred to as "bolting" or "shooting" to seed. It ends the commercial usefulness of the crop for market or canning.

Hereditary genetic factors play a part in determining the time at which flower stalks develop, as evidenced by the successful development of long-standing varieties, which may commence stalk-elongation 3 or 4 weeks later than other varieties. Considerable difference may exist between plants within a variety. Male plants usually bolt earlier than female. The time of development of the stalks is also markedly affected by environmental factors. Light is especially important. Garner and Allard (1920) show that spinach is a long-day plant, which remains in the vegetative condition during the short days of winter but forms flower stalks when the day is lengthened. Munerati (1924) reports that under continuous illumination, spinach flowers within 25 days from planting, while no tendency to flowering was noted after 60 days in plants grown under the usual diurnal changes in light. Rosa (1926) found that spinach will flower and set seed in December and January, with continuous illumination from 60-watt electric lights. The tendency of all spinach plants to form flower stalks in spring, regardless of the size or age of the plants, is more likely a response to the long daylight period than to the higher temperatures. Temperature no doubt has some effect, however, on the time and rate of flower-stalk development. Spacing of the plants also affects the type of growth. When crowded, the plants do not form a rosette of leaves but develop elongated stems from the beginning of the growth period.

Flowers.—The flowers are apetalous, small, and inconspicuous; they are borne in cymose axillary clusters of from six to twenty. There are three kinds of flowers—staminate, pistillate, and hermaphroditic; the

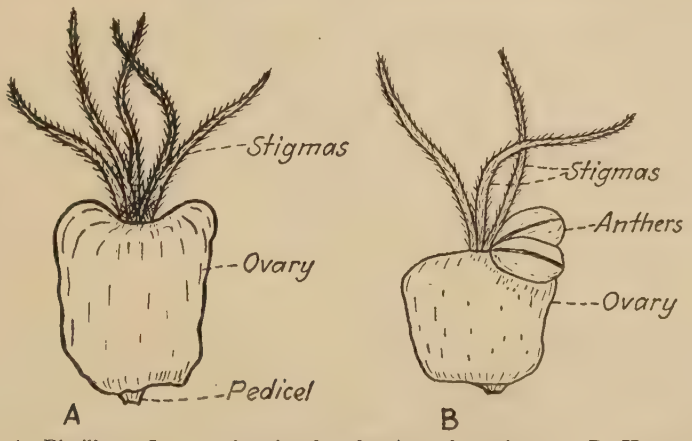

FIG. 22.—A. Pistillate flower of spinach, showing the stigmas. B. Hermaphroditic flower, two stigmas transformed to anthers.

first and second are usually found on separate plants. Hermaphroditic flowers are rare, occurring on plants where most of the flowers are pistillate.

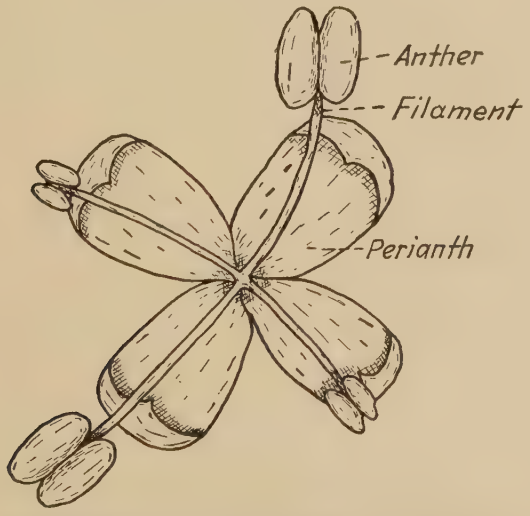

FIG. 23.—Staminate spinach flower. One pair of anthers is ready to dehisc.

Staminate flowers have a four-parted calyx, each segment subtending a stamen. Each stamen bears two, large, ovoid anthers, which become yellow a day before dehiscense. They dehisc by longitudinal splitting,

the walls curving back and exposing the masses of yellow pollen grains which are scattered by the wind. The four stamens in a flower do not dehisc simultaneously but one after the other, over an interval of several days.

Pistillate flowers have a two- to four-parted calyx, which encloses the ovary. The calyx persists to maturity and, with the pericarp, forms the hard, cartilagenous outer covering of the fruit. The ovary is one-celled and contains a single campylotropous ovule. It bears a single pistil with four to six stigmas, united at the base. If pollination is delayed, the stigmas continue to elongate. They are provided with numerous papillae, which catch and hold the pollen.

The hermaphroditic flowers are variable. According to Stomps (1910), their structure resembles that of the staminate flowers. Most of

FIG. 24.—Terminal shoots of flower stalks, showing sex expression in spinach. A. Female. B. Monoecious. C. Vegetative male. D. Partly vegetative male. E. Extreme male.

these observed by Rosa (1926) resembled pistillate flowers, in which one to three of the stigmas are replaced by stamens, the anthers of which appear to rest directly on the ovary.

Sex Expression.—With reference to the form of the mature plant and to the distribution of sexes, spinach may be termed tetramorphic. There are four main classes of plants:

Extreme Males.—These bear only staminate flowers, and the leaves on the upper portion of the flowering branches are suppressed entirely or reduced to small scales.

Vegetative Males.—These also bear only staminate flowers, but the leaves toward the tip of the flowering branches are fully developed.

Monoecious Plants.—These bear varying proportions of both staminate and pistillate flowers in the same cluster. The leaves toward the tips of the flowering branches are fully developed. Such a plant may be predominately staminate, predominately pistillate, purely pistillate early

in the season but with some staminate flowers later, or almost equally staminate and pistillate throughout the flowering period.

Female Plants.—These bear only pistillate flowers, and the leaves are fully developed to the tips of the stems.

Extreme males are most common in nearly all strains of the Prickly Seeded variety. In other varieties, the vegetative type of male is the more common. In strains carefully selected for the long-standing quality, vegetative males generally predominate. The difference between the extreme-male and the vegetative-male type is dependent upon genetic factors. Male plants, especially the extreme type, send up their stalks earlier, begin flowering earlier, and have a shorter flowering period than females. All male plants die at or before the completion of the flowering period.

Monoecious plants are relatively rare. In many strains, they are never observed. Smith (1920) reports as many as 4 per cent in some strains. The highest proportion of monoecious plants observed by Rosa in a commercial stock (1925) was in Long Standing, one lot of which produced 52.5 per cent males, 38.8 per cent females, and 8.7 per cent monoecious plants. Monoecious plants in spinach are obviously intersexual in their nature, as they occur in varying degrees of maleness or femaleness. Rosa (1925) found that the proportion of these intergrading forms was not affected by widely differing environmental conditions under which plants were grown. On the other hand, self-fertilized seeds from monoecious plants produce only monoecious plants. Monoecious strains, consisting of plants predominantly staminate, predominantly pistillate, or with varying proportions of staminate and pistillate flowers, have been isolated.

Sex Ratio.—While it is impossible definitely to identify male plants until after their stalks are well developed, the smaller plants are, in general, males. Conversely, the plants which are larger in the early part of the season are usually females. The extreme-male plants are an undesirable type from the grower's standpoint. The vegetative males, however, are very similar to females in form and method of development. The development of strains in which all the males are of the vegetative type seems desirable not only because of the elimination of the nonproductive, early-bolting, extreme males but also because the vegetative males more nearly coincide with the females in their flowering period, thus insuring end-season pollination. Such strains have been bred in Savoy and Long Season varieties by Zwaan (1925) and in the Prickly Seeded variety by Rosa. Nohara (1923) found that in spinach, male and female plants generally occur in approximately 1:1 ratio, while Zwaan (1925) states that certain strains produce an excess of males. Rosa (1925) found that a 1:1 ratio generally existed, though certain strains produced a slight excess of females; others, a considerable excess of males. The sex

ratio cannot be modified by differences in fertility of soil, spacing of plants, intensity of light, planting date, nor mutilation of plants, according to Rosa (1925). Sex expression in spinach is primarily controlled by genetic influences.

Pollination.—Pollen is transferred from the anthers to the stigmas by air currents. As with most wind-pollinated plants having small inconspicuous flowers, the pollen is produced abundantly over a long period. The pistillate flowers, if not pollinated, remain receptive for 2 or 3 weeks. On account of the generally existing dioecism, cross-pollination is the rule. Monoecious plants are potentially self-fertile, though under natural conditions, self-pollination is rare, because of protogyny. The distance pollen may be carried by the wind is not known, but Rosa (1926) found that female plants 300 yards distant from a group of males, with several rows of tall plants between and not in line with the prevailing winds, set very few seeds. These conditions, then, would be suitable for the isolation of seed plots of different varieties. On account of the small size of the pollen, it cannot be satisfactorily excluded by covering the pistillate plants with cloth cages.

Concerning the occurrence of parthenogenesis in spinach, conflicting statements have been made. Buzareinges (1856) and other writers report that isolated female plants set seed. Stomps (1910) concluded that parthenogenesis was not likely to occur in spinach, since his cytological studies of the pollen grains revealed no irregularities of the type usually found in apogamous plants. Female plants isolated by Stomp developed seed, but it was afterward noted that such plants had a few staminate flowers. This condition very likely existed in the experiments of those who have reported parthenogenesis in spinach.

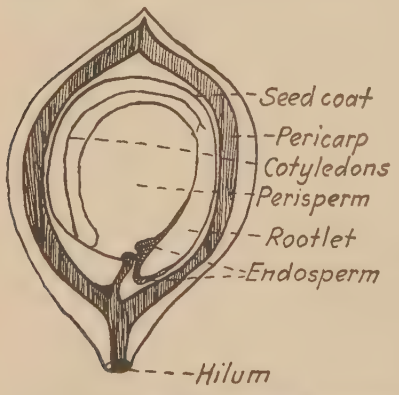

FIG. 25.—Section through a spinach fruit showing the embryo and the seed coverings. Round seeded variety. (*Redrawn from Harz*, 1885.)

Fruit and Seed.—Spinach produces a one-seeded fruit of the type known as an "utricle." It is closely enveloped by the persistent, hard, cartilagenous calyx or by calyx-like bracts. In one group of varieties, these bracts are drawn out into two, three, or four horny projections, or spines; these are lacking in round-seeded spinach. The pericarp is reduced to a thin, membranous layer enveloping the mature seed within the bracts. The whole fruit is commonly referred to as "the seed."

The one-celled ovary usually contains a single ovule, although Stomps observed some two-seeded fruits. He concluded that when there are

two ovules, they arise from the carpellary walls but that when there is only one, it springs from the base of the ovary. The campylotropous growth of the ovule results in a ring-shaped embryo, coiled around a large mass of perisperm. The amount of endosperm in the mature seed is very small; most of the tissue is perisperm. Starch is the main storage product. Spinach seed is used for making bread in the Orient.

Germination.—The relation of temperatures to germination in spinach was studied by Haberlandt, who reports that germination begins after 9 days at 4.7, after 5.7 days at 10.5, and after 3.2 days at 15.6°C. The ability of spinach to germinate at low temperature is often taken advantage of by planting during the fall or winter, even when the soil is frozen.

Spinach seed remains viable for a long period. Rosa (1926) found that seed of the Prickly variety, grown in California, germinated about 20 per cent after 9 years. The initial viability was not known. A short rest period is probably necessary, for the seeds germinate slowly and irregularly for two or three months after it becomes mature. The viability of commercial stocks of spinach seed is often as low as 75 per cent or even less. The non-viable seeds are found to contain shriveled embryos or no embryos at all. The former condition probably results when the plants die while the seed is in the milk or early dough stage. Parthenocarpic fruits are common, but they are usually small.

Soil Requirements

Spinach thrives on a wide range of soil types. The greatest yield is usually produced on heavy loam. Light, sandy soils are sometimes preferred for the winter crop. The color of the leaves is often yellowish on such soils, unless nitrogenous manures are applied. The plant is decidedly halophytic; in Arizona, it was found to thrive on soils too salty for lettuce (Albert, 1923). The reaction of the soil solution is very important; Hartwell (1914) found that almost no growth resulted on soil rendered acid by applications of sulfate of ammonia. Even when the acidity of the sulphate plot was neutralized with lime, four times as much growth resulted on the more alkaline soil treated with nitrate of soda. Zimmerley (1924), in Virginia, noted that low germination, yellowing and browning of the margins and tips of the leaves, and browning of the tap-root and rootlets occurred on acid soils. In an experiment where the soil reaction was controlled, Zimmerley found that the best growth occurred between Ph 7.33 and 8.22. The yield was slightly less between Ph 6.01 and 6.99 and much less between Ph 5.62 and 5.72, and there was almost no growth below Ph 5.22. Since nutrients were abundantly supplied, Zimmerley attributed those results directly to the reaction of the soil solution.

Climatic Requirements

Spinach is a hardy, cool-season plant. It will generally withstand temperatures as low as −10°C. without injury, though small seedlings and plants approaching the marketable stage are somewhat more tender. Some growth takes place at temperatures slightly above freezing, but the optimum growth temperature is higher. Hence, spinach is a typical winter crop in sections having mild climates. In northern regions, it is grown either as a fall or an early-spring crop.

Light duration influences markedly the method of the plant's development. A long day stimulates the reproductive processes. This is the main reason why spinach is seldom grown successfully as a summer crop. Low temperatures may modify the effect of light, for spinach is grown to some extent during summer in cool regions.

Climatic factors exercise considerable influence on quality in spinach. Magoon and Culpepper (1924) state that fall-planted spinach at Washington, District of Columbia, contained more sugar and total solids than did the spring-planted spinach. The development of succulent, tender foliage is favored by high atmospheric humidity.

Composition

Spinach leaves are rather high in carbohydrates and in proteins, but these vary considerably with the age of the plant and under different environmental conditions. The per cent of dry matter and the carbohydrate content are high when vegetative growth has been checked by low temperature. The following table gives the percentage composition of healthy Savoy spinach harvested in January at Norfolk, Virginia.

	Dry matter	Reducing sugars	Total sugars	Starch	Total nitrogen	Protein nitrogen	Total ash
Tops	11.7	0.59	1.50	0.84	0.59	0.31	2.27
Roots	21.4	trace	5.00	2.27	0.81	0.41	1.44

Spinach is remarkable for its high ash content, which consists largely of base-forming elements. The reaction of the cell sap in living tissue, however, is slightly acid, because of the organic acids present. According to True and Hawkins (1918), the more abundant elements found in the ash occur in the following order: K, Si, Na, P, Ca. Although spinach is considered especially rich in iron, these investigators found only 0.122 per cent ferric oxide in the dry matter. Osborne and Wakeman (1920) report that nearly one half of the total solids in spinach leaves are water-soluble. They found that spinach contained more N than did most other leaves, about one fourth of it being in protein form, the soluble nitrogenous constituents being much more abundant. Chibnall (1914)

isolated the principle protein of spinach leaves—spinacin. It occurs as an anion in the cytoplasm of the cells at a H-ion concentration slightly below its iso-electric point, which is between PH 4.0 and 4.6.

CULTURAL METHODS

Planting Date.—Spinach is planted in late summer and early autumn for a fall crop and in early spring for spring and summer harvest. Winter plantings are made in the warmer parts of the country. Sometimes the

FIG. 26.—Section through the crown of a spinach plant, showing the compressed stem and the rosette leaves, just before the flower stalk arises.

seed is sown in the northern states before the soil is free from frost. As far north as New Jersey, late-fall plantings are made for wintering over.

Planting Methods.—Small areas of spinach are often broadcasted, especially for the fall crop. This method is not generally favored, because of the difficulty in weed control and harvesting. The crop is usually drilled in rows, which may be from 10 to 24 inches apart, depending on the variety and the method of cultivation. The wider planting is followed where horse cultivation is practiced. Varieties which have small

plants, like Savoy and Long Season, are planted closer than large-growing types, such as Prickly and Thick Leaf.

When not irrigated, spinach is planted on level ground without beds except for the winter crop in the southern states. There, broad, low beds are made on which four rows are drilled. The furrow between the beds provides drainage during wet weather. Spinach is easily injured by water standing around the crown. Planting under irrigated conditions is on narrow beds on which one or two rows are drilled. The winter crop on the Pacific coast is grown without irrigation.

Beet drills and grain drills may be adapted for the sowing of spinach on a large scale. The amount of seed per acre will vary from 4 to 20 pounds, depending on the viability of the seed and the space between the rows. Often, commercial stocks of spinach seed are less than 50 per cent viable, while 80 per cent is considered standard.

Thinning.—Market gardeners, and truck farmers in the South and East, find it profitable to thin the seedling plants to 4 or 5 inches apart. Thinning is not practiced on the canning crop. Spacing of the plants should be regulated as far as possible by adjusting the rate of seeding.

Manuring.—Johnson and Zimmerley (1922) report that on spinach grown during the warmer part of the year, nitrate of soda, sulfate of ammonia, and tankage were about equally effective as the source of N, but that spinach receiving the sulfate was a darker green and of better shipping quality. When the crop was grown during the winter, the nitrate and sulfate were equally effective, but almost no crop resulted when tankage was applied. It was thought that the ammonification process, necessary to render the N in tankage available, was inhibited by the low temperature in winter. Spinach is probably able to utilize ammonia N directly. The darker color of plants fertilized with sulfate of ammonia may be attributed to the effect of the sulfate ion or to some indirect effect.

McLean and Gilbert (1925) find that chlorosis and arrested growth may result when Mn is absent or non-available, due to excessive alkalinity. They were able to correct this condition by spraying the plants with 0.004 per cent solution of manganous sulfate.

Where large amounts of commercial fertilizer are used, it is customary to divide it into applications before and after planting. Zimmerley (1924) finds, however, that for the fall crop with 1,200 pounds per acre of commercial fertilizer, excellent results are usually produced by applying the whole amount and working it into the soil before the beds are formed.

Harvesting

Spinach may be harvested at any time after five or six rosette leaves are formed, until the majority of the plants have formed flower stalks. The yield increases very rapidly during this period and, likewise, the percentage of waste becomes larger, due to the yellowing of the lower

leaves and the increase in the size of petioles and stems. Market gardeners usually harvest the larger plants first, making two or three cuttings for the entire crop. When the crop is used for canning, all the plants are harvested at once. Harvesting is the most expensive operation in spinach production, but the cost can be materially reduced by making only one cutting, even at some sacrifice in yield. The tap-root is cut just below the surface of the soil with a knife, garden hoe, or push hoe. The plants are sometimes pulled by hand and the tap-roots trimmed afterward.

The plants are allowed to wilt slightly, so that they can be packed in containers without injury. Because of the turgidity of the plants, spinach should never be cut when wet with dew or rain. When it is harvested and packed tightly in crates, respiration proceeds rapidly. The heat generated by respiration cannot escape, and this results in a rapid rise of temperature in the center of the container. Spinach should never be left in tightly packed containers longer than 5 or 6 hours, unless stored at low temperature.

Packing and Shipping

In Virginia and other Atlantic states, the burlap-covered barrel and round, bushel basket are the usual containers for spinach; in Texas, the round, bushel basket; and in the western states, the standard lettuce crate. In the latter, oiled-paper liners are used to prevent wilting, and the top layer is arranged to produce an attractive pack. Spinach is sometimes packed in the field, though usually it is hauled to the packing shed in bulk. Washing prior to packing removes grit and insects but results in considerable mechanical injury, so that shipping quality is impaired.

A soft rot, caused by *Bacillus carotovorus*, is the chief source of loss to spinach in transit. Ridley (1921) reports that spinach washed before packing and shipped in refrigerator cars developed, on the average, 37.3 per cent rot within 10 days, while similar lots not washed developed only 7.7 per cent rot. Unwashed spinach is more subject to loss by wilting and yellowing during transit, but Ridley found that this could be eliminated by putting crushed ice in the center and on the top of the package, in addition to the bunker icing of the car.

Marketing

Leading sections in the production of spinach for shipment are around Baltimore, Maryland; Norfolk, Virginia; Austin, Texas; and in southern California. Virginia supplies most of the late fall shipments and also has a considerable spring crop movement. Southern Texas ships heavily for a brief period in late winter. The southern California crop goes chiefly to Pacific coast markets during the winter. Because of its bulky nature and low market value, spinach cannot be shipped profitably from the

more distant sections, when nearby supplies are available. Most of the acreage for canning is in the Sacramento and Santa Clara valleys of California.

Canning and Dehydration.—Spinach for canning is usually grown during the winter and canned in March and April. It is the first vegetable available for canning operations. The crop is grown in large acreages, under contract to the cannery. In preparing spinach for canning, the discolored leaves are removed, most of the petioles are cut off, and plants with flower stalks are discarded. An intensive washing in rotating cylinders is then given to remove grit and insects. Smooth-leafed varieties are preferred for canning because of the large tonnage produced and the ease of washing. The following requirements for canning spinach have been formulated by the Canners' League of California (1926): "Spinach must run less than 30 per cent waste; the number of plants per pound must be 25 or less, with not over ¾-inch stems."

Spinach can be dehydrated commercially, an advantage being the greatly reduced bulk and weight of the product. The spinach is prepared as for canning, placed on trays, blanched in steam for 2 to 5 minutes, then dried for 6 to 10 hours, at 150°F. According to Nichols and Powers (1918), spinach should be dried to a moisture content of 5 per cent or less, then conditioned for packing by increasing the moisture content to 6 or 7 per cent, by exposure to moist air. It was found that spinach with a greater moisture content is subject to molding; since the dried product is quite hygroscopic, it has to be packed in air-tight containers.

Varieties

The many varieties of spinach studied by Goff (1887) were not very different from those now in use. Kinney (1896) collected all available varieties and classified them into four varietal groups. During 1923 to 1926, Rosa (1926) tested 121 varieties obtained from American and European sources and concluded that there were only five distinct varietal types, one of which, Long Season, apparently had been developed since Kinney's time.

The numerous varietal names of spinach are, for the most part, synonyms or apply to strains varying by slight or non-constant differences. Probably because of the dioecious nature of the plants and the universal occurrence of cross-pollination, spinach varieties are generally very variable within themselves. Below are given the chief characteristics of the five varietal groups. All of these have round seed, except No. 5.

1. Savoy.—The rosette leaves are erect, forming a tall, vase-shaped plant. The leaves are much crumpled, with down-curved margins. This is one of the earliest and most attractive varieties from the market standpoint. The thick, crumpled leaves are also supposed to withstand

handling and shipping especially well. The staminate plants are mostly of the vegetative type. The principle defects are the tendency of the plants to form flower stalks very early, and the light yield as compared to certain other types. Savoy spinach is used most extensively by market gardeners in northern states and for the winter crop in Virginia and the Carolinas.

The original strain of this variety was the Bloomsdale Savoy, introduced to the United States in 1828 by David Landreth, of Bristol, Pennsylvania, who probably brought it from Holland. A somewhat improved strain, Norfolk Savoy-leaved, was introduced by Peter Henderson in 1875. A strain resistant to Mosaic blight, Virginia Savoy, was developed in 1920 by the Virginia Truck Experiment Station. In 1926, A. R. Zwaan, of The Hague, Holland, introduced Long-standing Savoy, a strain which does not produce flower stalks so early as other strains do.

2. Thick Leaf.—The rosette leaves are spreading, and, with ample space, a large plant is formed. The leaves are very broad, hastate, long-petioled, and slightly crumpled near the base. The plants are moderately rapid growers, do not, in general, tend to form flower stalks early, and produce a large yield. The staminate plants are of both the vegetative and the extreme types. Thick Leaf varieties are used to some extent for market purposes but are most desirable for canning.

The Thick Leaf type was apparently introduced in America about 1863. Kinney states that it was probably derived from a very large variety grown in Holland for over three centuries. The number of varieties belonging to this type is now very great; Giant Thick Leaf, Viroflay, Monstrous Viroflay, Gaudry, Belgian Evergreen, and Eskimo Giant are some of the best known.

3. Long Standing.—Two rather distinct varieties belong to this type —the round-leafed varieties described by Kinney and certain recent introductions, such as King of Denmark. The former is characterized by short-petioled, broad, round-tipped, smooth leaves; the latter has long-petioled, broad, hastate leaves. Both classes have deep-green, thick, leathery, smooth leaves, produce rather small plants, grow very slowly, and stand for a long time without forming flower stalks. The varieties of this type are useful only for the late spring market crop. The extreme degree of the long-standing characteristic is apparently not attainable without slow growth and decrease in size of plant.

Varieties of this type are apparently of rather recent origin and are the result of intensive selection, chiefly for late development of the flower stalk. A variety called Long Standing was listed by Bliss in 1866. Victoria was introduced in 1894 from Germany by W. A. Burpee. The Lettuce Leafed variety probably existed in France much earlier. The King of Denmark (*Antvorskov*) was introduced in 1920 by Joseph Harris, of Coldwater, New York, from a European source.

Varieties sold as Long Standing are often of the Thick Leaf type.

4. Long Season.—The rosette leaves are short-petioled, forming a low, compact plant. The leaves are small, much crumpled at the base, very thick, rather narrow, and sharp pointed. The plants grow very slowly, attain only medium size, and form flower stalks late in the spring. This type is useful only for late spring cuttings.

The variety Long Season was introduced by Peter Henderson in 1903. Similar varieties are Triumph and Juliana.

5. Prickly Seeded.—The varieties belonging to this group have spiny or prickly seed but, apart from this one character, are extremely variable. Prickly Seeded is supposed to be the original variety of spinach; some strains, however, have evidently been much modified in recent years by intercrossing with the Thick Leaf type and by selection. The plant type usually associated with the Prickly Seeded variety is characterized by long, narrow, extremely sagitate rosette leaves, long petioles, smooth leaf-blade, pale-green color, staminate plants of the extreme type only, and a tendency to form seed stalks early. Strains having the foregoing characteristics are very poorly adapted to any type of culture. Many strains are available, however, which have been much improved in plant characteristics and which differ from the Thick-Leaf group mainly in the shape of seed and the types of staminate plants.

The Prickly Seeded type is used chiefly for the canning crop on the Pacific Coast. There is a tradition, handed down for hundreds of years by writers on spinach, that this type possesses greater hardiness than other varieties and it has therefore been recommended for winter plantings. As long ago, however, as 1870, Peter Henderson stated that there was little evidence for this belief.

Names applied to this type are Prickly Seeded, Prickly Winter, Long Leaf Winter, Amsterdam Giant, and Hollandia. The latter two are of the improved type. The Manchurian spinach probably represents the primitive form of this variety. Stocks resembling the Manchurian were imported in 1918, and became known as Japanese Prickly.

Breeding

Stomps (1910) studied nine varieties of spinach and found six to be the haploid number of chromosomes in every case. He found groups of cells in the root tips of some plants, however, wherein the tetraploid-chromosome number occurred. Such cells were much larger than the ordinary diploid cells. The chromosomes may be identified by their differences in length.

Nohara (1923) made crosses between smooth and prickly-seeded varieties. The prickly character is dominant in the F_1, and a 3:1 ratio is obtained in the F_2. Nohara could find no differences in the male plants to indicate which ones carried the factor for spiny seed.

Smith (1920) tested numerous varieties for resistance to the Mosaic blight at Norfolk, Virginia, in 1916 and 1917. Only the Manchurian showed any appreciable resistance, in fact this variety was almost immune. The immunity was thought to be due in part to its non-attractiveness to aphis. Crosses between Manchurian and Bloomsdale Savoy were utilized in the development of a resistant strain of the Savoy type. The F_1 generation was intermediate in susceptibility to blight and in plant characters, though the savoyed leaves of one parent and the long petioles of the other seemed to be partially dominant. Continuous selection of plants having the plant characters of the Savoy variety and the blight resistance of the Manchurian, yielded in the fifth generation a fairly uniform strain combining these qualities to a satisfactory degree.

The inheritance of sex in spinach furnishes an interesting field of study. Stomps noted that seed formed by isolated female plants and which had a few male flowers gave rise to progeny that were almost exclusively female. Rosa (1926) found that monoecious plants, self-pollinated, produced monoecious plants only. In the progeny, all the plants of some strains were predominantly pistillate; others, almost entirely staminate; and others, intermediate. Pistillate plants pollinated by monoecious plants gave rise to families of approximately equal numbers of monoecious and pistillate plants. Monoecious plants pollinated by staminate plants produced all three types. Recessive characters appearing in inbred lines were bright red pigmentation of the fruit bracts, stems, and anthers, chlorotic leaves and greatly decreased vigor.

Zwaan (1925) obtained, by selection, strains of the Long Season and Prickly Seeded varieties, which produced male plants almost entirely of the vegetative type. These strains continue to produce a small proportion of the extreme males in each generation, however. The genetics of the type of male plant has not been worked out, but the difference between the vegetative and extreme types probably depends upon several factors.

Seed Production

Holland has long been the center of spinach seed production. Denmark, Germany, and Belgium also send some spinach seed to the United States. During the World War, large quantities were grown in the United States, but now American seedsmen are again procuring most of their spinach seed abroad. The lower cost of production in Europe, because of the cheap hand labor available, is the main reason for growing it there. Contrary to popular opinion, the best American-grown stocks are as good or better than those imported. Some spinach seed is still grown on Long Island, in California, and in the Puget Sound district.

For seed production, plantings are made during the winter or early spring. The larger the plants become before flower stalk formation

begins, the greater the yield of seed. Unless the seed is sown thinly or the small plants are thinned, it is not possible to rogue effectively. Before the flower stalks appear, the field should receive its first roguing. All plants not true to varietal type should be removed. A few days later, a second roguing is necessary, to remove the plants which show early flower stalks. Most of the plants removed at this roguing are males, and their elimination does not reduce the yield of seed. The males which appear somewhat later will be ample for pollination purposes. Since spinach is generally heterozygous for many characters having to do with the commercial value of the plants, the occrrence of some off-type plants is to be expected every year. Unless they are removed, the quality of the strain deteriorates. The need for such extensive roguing can be eliminated by the establishment of pure lines which are homozygous for the desired characters. Such lines will have to be carefully guarded from cross-pollination by other varieties, or lines.

Since spinach seed shatters badly from plants that are dry, the plants should be mowed before they are fully mature. After curing in the field for a few days, the plants are placed on canvas sheets, and the seed is separated by use of heavy rollers. The final cleaning is performed with a fanning mill. About 600 pounds per acre is a fair yield of seed.

Diseases

Downy Mildew or Leaf Mold (*Peronospora effusa*).—Serious losses are caused by the downy mildew in late fall and early spring, though the severity of the disease depends largely on weather conditions. Downy mildew usually accompanies or follows warm, humid conditions. The upper surface of affected leaves have large, irregular yellowish areas. On the under side of the leaves are patches of the dense grey mat composed of mycelia and fruiting bodies of the fungus. The greater portion of the leaf may become infected, if conditions are favorable. The affected areas eventually wither and fall out, resulting in ragged leaves. The older leaves, being nearer the ground and in a more horizontal position, are chiefly affected. These have to be removed in preparing the plants for market or for canning.

Kinney (1896) suggested that the oospores of the fungus are carried on the seed. Newhall (1925) reached the same conclusion. He found no evidence of the fungus on wild host plants, except on *Chenopodium album* (lamb's quarter), and the fungus did not seem to spread from this plant to spinach. Smith (1921) reports that spraying the plants twice with copper-soap solution checked the development of the disease, while Bordeaux mixture and Bordeaux soap had no beneficial effect. Special apparatus for spraying spinach has been devised by Zimmerley and Smith (1919), but the effect which the spray material might have on the quality

of spinach from the standpoint of the consumer or the canner, has not been determined. No evidence of varietal resistance has been found.

Leaf Spot (*Heterosporium variable*).—In the Atlantic coast states, this disease often injures the quality and lowers the yield. Small, brown spots appear on the leaves, and with warm, moist weather, these enlarge, causing the leaves to turn yellow, while a greenish-black mold appears on both sides of the leaves. As only non-vigorous plants are subject to infection, good soil conditions are the best preventative.

Rust (*Puccinia subnitens*).—In Oregon, severe injury has been reported on spinach by a rust disease with bright orange cluster cups. According to Barss (1922), the fungus passes the summer on an alternate host—the salt, or alkali, grass, *Distichlis specata*. The telial stage of the fungus was found on this plant, from which infection spread to spinach and beets.

Wilt (*Fusarium spinaceae*).—Although reported only from Idaho, wilt diseases of spinach caused by this or other species of Fusarium probably occur in other regions. The leaves of affected plants turn yellow, and the older leaves roll inward along the midrib, then eventually die. The fibrous roots are destroyed, the tap root is scarred and blackened, and the vascular tissue of crown and root is discolored. The causal fungus lives in the soil, and rotation of crops is the only control measure known. Since Fusarial diseases progress slowly at low temperatures, serious loss is not likely to occur on spinach in the cooler portion of the season.

Taubenhaus (1924) reported a wilt disease, caused by *Fusarium solani*, of widespread occurrence in Texas. In California, wilt diseases of undetermined cause are a source of much loss on the seed crop, which is of necessity exposed to a period of high temperatures during maturation. Early fall plantings of market spinach in the warm interior valleys are also seriously injured by wilt.

Mosaic.—A disease which for many years had been very destructive of spinach in Virginia, where it is commonly termed "blight," was proved by McClintock and Smith (1918) to be of the infectious virus type. This disease causes malformation and yellowing of the younger leaves, with mottling of the older leaves. Growth ceases, and the plants gradually disintegrate. The disease has been discovered in many other states. It is generally most destructive during the cooler part of the season. The pink and green potato aphis and the peach, or spinach, aphis, were found to be the chief agents in the transmission of the virus from plant to plant. The answer to the question of how the virus passes the summer season, when spinach plants are not available, is suggested by the fact that the virus may be transmitted in the aphis. Smith found that infective aphis reared for four viviparous generations on plants other than spinach were able to cause the disease when they fed on spinach. No evidence of alternate host plants for the virus was discovered, nor is the disease transmitted in the soil or by the seed.

Efforts to control this disease through fertilizer applications and soil amendments gave negative results. Smith found that the disease could be reduced to a minimum on the fall crop by the control of aphis through careful spraying with nicotine solutions. This, however, is not often practical on the winter crop, because of weather conditions. The common varieties of spinach showed little or no resistance to the disease, but the resistant factor was found in the Manchurian variety, which was used to breed a resistant variety of the Savoy type.

Malnutrition.—A physiological disorder of a non-infectious nature but resembling the mosaic disease in its general effects on the plant, occurs in Virginia and probably elsewhere. According to Smith (1920), this trouble is distinguished from mosaic by the absence of malformations and of mottling; the presence of red color on the petioles and on the basal portion of the leaves, and the "savoying" of the leaves is more or less reduced. The plants are reduced in size, appear flattened, eventually turning yellow or red, then die. Its occurrence in some cases has been connected with excessive acidity of the soil solution, the application of lime having a beneficial effect.

Curly Dwarf of Beet.—Carsner (1919) reports the occurrence of this virus disease, common on beets in the western states, on spinach in California. The disease is spread chiefly by the beet leafhopper, and, since these are not numerous during the cooler part of the year, the disease is seldom important on market spinach. The seed crop is often attacked, however. The leaves become crumpled, turn yellow, and die. This disease kills spinach plants more rapidly than it does beets.

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PART V

CRUCIFERAE

The *Cruciferae* are of considerable economic importance. This family probably possesses a larger number of crop plants than any other.

The cultivated crucifers of importance as vegetables crops in America are *Brassica oleracea* var. *capitata* (cabbage), *B. o.* var. *botrytis* (cauliflower), *B. o.* var. *acephala* (kale), *B. o.* var. *gemmifera* (Brussels sprouts), *B. o.* var. *caulo-rapa* (kohl-rabi), *B. rapa* (turnip), *B. napobrassica* (rutabaga), *B. juncea* (Chinese mustard), *B. pekinensis* and *B. chinensis* (Chinese cabbage), *Raphanus sativus* (radish), and *Armoracia rusticana* (horse radish). Many of our common weeds, which have been introduced from Europe, belong also to this family.

CHAPTER VII

BRASSICA

The wild cabbage, *Brassica oleracea*, found growing at the present time on the coastal regions of western Europe, is thought to be the progenitor of our present varieties of kale, Brussels sprouts, cabbage, cauliflower, and kohl-rabi. It is not known whether each one of these sub-species traces its ancestry directly back to the native species or whether each has descended one from the other. While they show a great diversity of form in their vegetative characters, their floral characters are very similar, and they cross readily.

SECTION A. CABBAGE

According to Sturtevant, cabbage is distributed over most of the world. It was known to the ancient Egyptians, Greeks, and Romans. It was introduced into America at an early period, and it is mentioned as growing in Haiti in 1556, in Virginia in 1669, and in New York in 1779. In 1828, Thorburn listed 18 varieties in his seed catalog. Goff (1886), described 70 varieties. Myers and Gardner (1919) state that 54 representative seedsmen listed 243 varieties in 1915. No doubt a considerable number of these were synonyms.

Plant Characteristics

The cabbage plant does not grow so tall as broccoli, cauliflower, Brussels sprouts, and many varieties of kale. The stem is short the first year and produces a single terminal bud, the "head." The second year, the stem elongates and branches.

Roots.—Thompson (1920) studied the root system of cabbage, at Ithaca, New York, on Dunkirk gravelly sandy loam. Roots penetrated to a depth of 30 inches—even the finer roots were found in considerable numbers as deep as 24 inches—but most of the root system was found in the upper 12 inches—the surface soil. The roots were branched many times, so that the soil was well filled to a depth of 6 inches, although the greatest mass was found within 3 inches of the surface. The roots extended laterally as far as 3 feet and were about as plentiful midway between the rows as within a few inches of the plant. Most of the cabbage roots are small but are of about the same size throughout their length.

Leaves.—The leaves are large and at maturity are oblong—ovate to nearly circular; the larger leaves taper to a very short, broad-winged

petiole. The leaves of the flowering stems are mostly prominently toothed and semi-clasping at the base.

Inflorescence and Flower.—The inflorescence is a terminal raceme. The flower is perfect and regular, with four sepals, four petals, six stamens, and a two-celled ovary. The sepals are in two distinct whorls; they fall early. The corolla has the appearance of a Greek cross and is whitish yellow. The six stamens are in two whorls, the outer one consisting of two short stamens opposite each other, and the inner, of four long stamens. The anthers dehisc longitudinally. The pistil is superior and two loculed.

Pollination.—The flowers are almost entirely insect pollinated. The two shorter anthers are sometimes on a level with the stigma but generally not so high. These curve outward, but their pollen-covered sides face the center of the flower. The pollen-covered surfaces of the long stamens

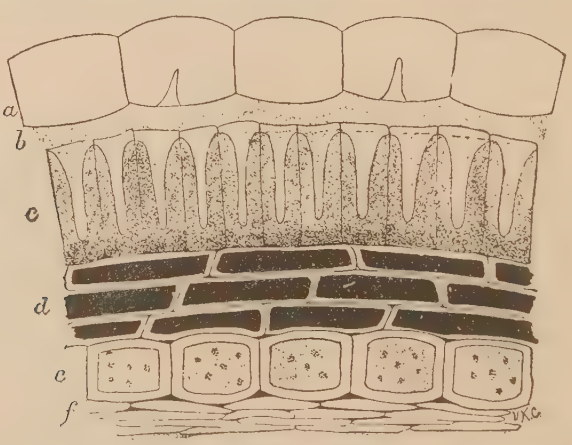

FIG. 27.—Section through outer part of seed of Brassica oleracea; a. epidermis, b. cells obliterated; c, supporting layer; d, pigment layer; e, proteid layer and f, endosperm. (*Pieters and Charles*, 1901.)

also face the center of the flower. The four nectaries secrete considerable nectar, and it is probably while gathering this that the insect visitors cause either cross- or self-pollination.

Fruit.—The fruit is a long, slender silique, terminated by an indehiscent and seedless beak.

Seed.—The seed is campylotropous. The large embryo fills the seed and the cotyledons are conduplicate. The endosperm is almost entirely lacking. The seeds of cabbage, kale, cauliflower, kohlrabi, broccoli, Brussels sprouts, and collards appear similar even under the microscope. Pieters and Charles (1901) have shown that six layers surround the embryo. Beginning at the exterior, these are (1) epidermis, (2) a layer, between epidermis and supporting layer, has its cell structure entirely obliterated, (3) supporting layer, (4) pigment layer, (5) proteid layer,

and (6) endosperm. The epidermal layer is mucilaginous and swells upon the addition of water. The three or four rows of cells in this pigment layer are of great value in distinguishing this from other species. These cells are generally rectangular in cross-section and are filled with a dark-red pigment. Kotowski's (1925) results seem to show that size of seed does not effect yield. The quality and yield from small seed was as good as from large seed.

Climatic and Soil Requirements

Cabbage is a cool-season crop and makes its best development in those localities where it can grow to maturity in a cool and equable temperature. It is grown as a winter crop in the South, as a summer crop in the North, and as a spring and fall crop in the intermediate states. In California, cabbage does best in coastal regions where the climate is subject to the modifying influence of the ocean. In these and similar regions this crop grows well throughout most of the year.

Cabbage grows well on a variety of soil types. For an early crop, it is best to plant on a rich, sandy, or sandy-loam soil. But if large production is the main object, then the heavier types of soil should be used. The work of Hartwell and Damon (1914) seems to show that the cabbage does best on soils which are slightly alkaline. When grown on an acid soil, this crop is benefited by application of lime.

Kotowski (1926) sowed cabbage seed of the Copenhagen Market variety 2 centimeters deep in quartz sand at temperatures varying from 4 to 30°C. As shown in Table 20, no seedlings appeared above ground when held at 4°C. When, however, seeds held at this temperature for 60 days were transferred to 30°C., good germination was obtained. At 4°C., there is some growth of the radicle, but the growth of the hypocotyl seems to be inhibited.

Table 20.—Germination of Cabbage Seed at Different Temperatures (*Kotowski*, 1926)

Temperature, °C	4	8	11	18	25	30
First seedling, days after sowing	0	16	12	5	4	3
Last seedling, days after sowing	0	23	22	15	13	6
Seedlings in per cent of seed sown	0	78	64	64	63	52

Knott (1925) has shown that soaking seed for a period of 24 hours before planting does not influence the later growth and yield, if the plants from the soaked and dry seed appear above the ground simultaneously.

Cultural Methods

Growing Plants.—The method used in the growing of plants depends largely upon the locality and the season of the year in which the plants

are started. (1) For the early crop in the North, the seed is often sown in flats in the greenhouse or hotbeds and reset once or twice before transplanting to the field. (2) The seed may be sown thinly in flats or hotbeds and not reset before transplanting into the field. (3) Where conditions are not too severe, the seed is sown and the plants are grown to maturity in cold frames. (4) If plants are started during the summer months, the seed is usually drilled in rows in open beds. Most of the plants are started this way in the South, as are also those for the fall crop in the North.

When planting the seed in greenhouses, hotbeds, or cold frames, it is usually best to sow in rows 3 to 4 inches apart, especially if the seedlings are not to be "pricked-out." Seeds should be scattered thinly in the rows to prevent a spindly growth and damping-off of the plants. Watering should be done thoroughly and not too often.

Hardening.—It is almost the universal practice among gardeners to harden cabbage plants before transplanting them into the field in order to make them more resistant to freezing and better able to withstand the injury incident to transplanting. Hotbed and greenhouse-grown plants are usually hardened by gradually exposing them to lower temperatures for a period of 10 days or more and also by withholding water. Plants can be hardened by any practice that will check their growth.

According to Rosa (1921), the following changes accompany hardening: (1) a slowing up of the growth rate; consequently, hardened plants are much smaller and stockier than tender plants of the same age; (2) in hardened plants, the leaves are more tough and leathery; (3) the waxy covering, or "bloom," on the leaves is heavier; (4) the leaves are a deeper green; (5) the development of a pink color (probably anthocyanin) is especially pronounced in the stems, petioles, and leaf veins; (6) the palisade cells are smaller; (7) there is a considerable increase in the percentage of dry matter; (8) a decrease in the percentage of freezable water; (9) a decrease in the transpiration rate per unit of leaf area; (10) an increase in the amount of hydrophilous colloids, especially pentosans; (11) an increase in both reducing and total sugars; and (12) a decrease in starch.

No doubt, the most important changes occurring during hardening are those which increase the water-retaining power of the plant cell and consequently reduce the transpiration rate and the percentage of freezable water. The chief factor that operates here is the increase in dry weight and colloid content. Harvey (1918) is of the opinion that the amount of bloom, or waxy covering, is of considerable importance in the protection of plants against freezing injury. He suggests that water freezing on the leaf surface inoculates the undercooled solution within the leaf and that an increase in amount of bloom prevents the accumulation of water on the outside of the leaf and thereby permits a greater degree of undercooling. Harvey found that, during hardening, the proteins are changed to more simple forms, such as amino acids, which are less easily precipitated.

Transplanting.—Under non-irrigated conditions, the plants are set on the level, but, under irrigated conditions, the usual practice is to set the plants in the bottom of a furrow or on the side of a ridge. As they grow, the furrow is gradually filled, and later, the furrow is made midway between the rows.

The plants may be set by hand with a dibber or with transplanting machines, if large acreages are planted. The distance of planting depends mainly upon the variety. Such large-growing varieties as Late Flat Dutch and Succession are usually set 3 by 3 feet apart. Early, small-growing varieties, like the Wakefield and Copenhagen Market, are usually planted about 18 inches apart in the row.

Cultivation.—In a study of the effect of cultivation on the yield of cabbage, Thompson (1920) found that the yield was greater on plots that were scraped to kill weeds than where they were kept down by cultivation. The cultivated plots yielded an average of 124 pounds, while the scraped plots gave an average of 143 pounds. No doubt, a large number of the surface roots are injured by cultivation, a fact which accounts for a yield below that of the scraped plots. The best results will be obtained by a system which will keep the weeds under control and still destroy a minimum amount of roots.

Bolting.—In many localities, especially in the South, where the weather is mild during the winter, cabbage seed is often sown sometime during the fall and plants set in the field in early winter. The amount of growth made by these plants during the winter depends upon the location. In the more northern range where this practice is in vogue, there is very little growth for a number of weeks during the winter; there is probably, however, a considerable extension of root system. It has generally been thought by most growers and investigators that if conditions favor a uniform and steady growth, even though this growth may be very slow, only a small percentage of the plants will form seed stalks instead of heads. Conditions or practices which give the plant a severe check are thought by many to cause the plants to bolt. The tendency to bolt has been shown to be due in part to hereditary factors. In some varieties and strains, the tendency to bolt is much greater than in others. Zimmerley (1921) states that the Copenhagen Market variety has proven unprofitable for the early crop in eastern Virginia, because it has a marked tendency to produce seeders when the plants are started in the fall. There was also a considerable difference in this regard among the strains of Early Jersey Wakefield. In this latter variety, it was found that strains which form small compact heads early in the season are less likely to seed prematurely than those which are somewhat open-headed and leafy.

In England, varieties are of two general types (Sutton, 1924). One group is planted in August and overwintered for heading the following

spring; the other group is planted in the spring, because, if overwintered, most of the plants bolt. Both groups, however, are more or less affected by seasonal conditions. If the winter varieties are planted too early or if the weather remains mild, permitting excessive development before winter, even the winter varieties tend to bolt. In crosses between bolting and non-bolting strains, the F_1 produced all non-bolting plants.

Boswell (1925), working in Maryland with the varieties Early Jersey Wakefield and Warren Wakefield, found that the later the plants were started in the fall the less was the percentage that went to seed. The late-started plants are smaller in their overwintering stage than the early-started plants. More recently, Boswell has found that when plants are started somewhat earlier on poor soil, they grow slowly and harden well, and plants of relatively small size are overwintered which form a relatively low percentage of seeders in the spring. The large size of transplanted overwintering plants rather than the age was found to be the factor most closely associated with the formation of seed stems.

Harvesting.—Harvesting should not be done until the heads have attained the maximum solidity for the variety in question. In some localities, and at certain times of the year, it is necessary to cut as soon as the heads are firm, because there is danger of their bursting, especially if the crop matures during hot, moist weather. If the crop matures during the cool season of the year, the heads will remain in a prime condition for a long time without danger of loss. Care should be taken not to bruise the heads while they are being harvested.

Early cabbage is usually harvested as soon as the heads reach maturity. The heads, with a number of wrapper leaves attached, are cut and thrown into horse-drawn carts, which are pulled just ahead of the cutters. The late crop is usually not cut until the entire field is mature, although the time depends somewhat on general market conditions.

Marketing

Grading.—Rigid grading is of utmost importance, especially if the crop is to be shipped for a considerable distance. Standard grades for cabbage have been established by the Bureau of Agricultural Economics of the U. S. Department of Agriculture. These grades serve as a guide for the growers and packers in the grading of their produce and aid state and federal inspection at the point of shipment and upon arrival at destination. The specifications for U. S. grade No. 1 require that stock be fairly firm, free from soft, withered, puffy, or burst heads, and free from seed stems and soft rot as well as from damage caused by freezing, disease, or insects, and by mechanical or other means. As to size, U. S. grade No. 1 may be classed as small, medium, large, small to medium, or medium to large.

Packing.—Most of the early cabbage is shipped in crates, barrels, or hampers. Shipments sent long distances usually carry better in containers, especially if the weather is warm, as circulation of air throughout the load can be obtained. Rough handling in packing should be avoided, as it causes bruises that facilitate the entrance of decay organisms. Cabbage loses water during transit, so the crate should be given a good bulge to allow for shrinkage. Heads packed tightly are less liable to be injured than when they are free to move within the crate.

Bulk Loading.—A part of the early crop and most of the main crop is shipped in bulk; stock cars, box cars, and refrigerator cars are used. In the early sections, where bulk shipment is practiced, and in the forepart of the northern season, refrigerator cars are preferred. They can be refrigerated or ventilated in hot weather and heated in cold weather. A ventilating shaft, in the shape of a box or inverted V, is laid lengthwise along the middle of the car floor. There are also ventilators made of metal with sides of coarse screen instead of wooden slats. If the common box cars are used in warm weather, slats are nailed against open doorways, thus providing side ventilation in addition to the flue. The cabbage is piled, stem down, to a little more than half of the height of the car. Farther north, in cool weather, heavier loading is practiced. The usual method of loading cars of late cabbage in bulk is to place it by hand and to build the load up by tiers.

The great bulk of main-crop cabbage is shipped during cool fall weather. Many of the early shipments, especially of domestic cabbage, are in stock cars; but more cabbage is shipped in ventilated box cars than in any other kind, mainly because other cars are not available during the season of heavy movement. When box cars are used late in the season and there is danger of freezing in transit, the car is lined with paper, and the load is covered with a layer of straw; but the refrigerator car, with its protected side walls, is the standard after the beginning of freezing weather.

Production Areas

Early Crop.—Florida, Texas, South Carolina, Virginia, and California produce about five-sixths of the early-cabbage shipments. Florida is the largest early-cabbage-producing section. Some of the crop is marketed in southern cities, but most of it goes to the large markets from Pittsburg eastward. The early-cabbage-producing areas of Texas are limited almost entirely to the irrigated land along the lower Rio Grande River. A considerable part of the cabbage from Mississippi is shipped in mixed cars. In California, the most important early-cabbage sections are in the southern counties, Los Angeles, and Orange. Considerable early cabbage is also shipped from the Colma district, near San Francisco.

The main market for the California early crop is the Rocky Mountain and Pacific coast states. The two early-cabbage-shipping sections of Virginia are the Eastern shore and the Norfolk sections; the market is chiefly in the large cities of the Northeast. In South Carolina, the principal cabbage sections are near Charleston and Meggett; there is also a smaller area around Beaufort.

Main Crop.—New York and Wisconsin grow most of the late crop. The largest shipping section for the late crop is that of western and central New York. Domestic cabbage is produced in considerable quantity for the fall and winter market and for kraut. Red cabbage is produced to a limited extent only, but considerable of the savoy type is grown on Long Island. The Danish type, which supplies the winter market from storage, is by far the most important. Cabbage growing in Wisconsin is localized in the southern part of the state. About two-thirds of the planting is of Danish type. The market for Wisconsin cabbage is mainly in Chicago, St. Louis, and Kansas City. Shipments from Michigan are made from the field until November, after which the movement is from storage. A large part of the crop goes to Detroit, Cincinnati, Indianapolis, Chicago, and New Orleans. Much of the commercial crop from Colorado is shipped during late summer and early fall. The Denver district ships much of its cabbage in mixed cars with other vegetables. In Washington, cabbage production is largely localized in the Puget Sound and Walla Walla districts. In both districts, early and late varieties are grown for the neighboring markets. Early cabbage moves from the Walla Walla district in June and July as far East as Minnesota and to the cities of Northwest Canada. The Puget Sound district ships late cabbage chiefly to the nearby markets.

Shipping Seasons and Carlot Movements.—Florida and Texas are by far the heaviest shippers of early cabbage during the winter and early spring. California does not compete very strongly with these two states on the eastern markets, mainly because of high freight rates. If the northern late crop is below the average, or if the southern acreage is small or the yield low, there may be a demand for California cabbage at a price which will make eastern shipment profitable. Shipments from Alabama, Mississippi, Louisiana, and South Carolina compete with the late receipts from Texas and Florida. Shipments from the intermediate states follow those of the early crop. The main, or late crop, occupies the market to a large extent during the fall and winter. South Carolina, Louisiana, Texas, and California produce two crops of cabbage, one maturing in winter and called the "second crop" and the other, maturing in spring, called the "early crop." Late, second-crop, and early cabbage are found on the larger markets simultaneously during the first months of the year. In Tables 21 and 22 are given the shipping seasons and the carlot movements for the various districts.

TABLE 21.—SHIPPING SEASONS AND CARLOT SHIPMENTS OF CABBAGE BY STATES OR DISTRICTS, 1922–1926

States or districts	Shipping season	1922	1923	1924	1925	1926[1]
Alabama	February to June	1,366	1,561	904	1,270	1,586
Arizona	April to June	1	24	8	19	42
Arkansas	May to June	8	13	2	19	40
California	October to June	738	683	370	644	670
Colorado	July to February	1,889	3,134	1,571	1,396	1,342
Florida	December to May	3,002	1,225	3,796	1,933	1,750
Georgia	February to July	151	105	50	91	66
Illinois	June to November	144	289	279	198	195
Iowa	June to November	560	391	542	267	415
Kansas	June to July	12	9	30	63	67
Kentucky	June to July	73	85	107	45	17
Louisiana	January to June	349	449	95	646	332
Maryland	June to July	448	219	510	238	165
Michigan	August to March	871	705	669	583	245
Minnesota	August to March	1,156	981	1,555	909	1,098
Mississippi	April to June	1,629	1,134	605	674	1,031
Missouri	June to July	16	22	74	140	112
New Jersey	June to July	68	71	43	31	54
New Mexico	June to November	57	48	40	61	173
New York	August to April	9,785	9,121	11,025	13,374	12,241
North Carolina	April to November	213	364	263	371	345
Ohio	June to November	590	538	656	413	508
Oregon	October to February	4	6	85	40	173
Pennsylvania	July to March	348	310	294	642	499
South Carolina	November to June	3,365	4,327	1,398	3,372	2,704
Tennessee	May to July	563	270	348	317	609
Texas	November to July	3,996	1,368	7,258	4,024	6,259
Utah	August to March	28	28	40	89	62
Virginia, Eastern Shore	May to June	1,269	664	673	698	420
Virginia, Norfolk Section	May to June	640	1,589	1,223	990	821
Virginia, other sections	July to November	1,035	1,078	1,507	525	567
Washington	All year	99	108	78	89	164
West Virginia	June to July	29	26	25	22	57
Wisconsin	August to March	5,452	6,218	4,903	5,707	4,622
Total for United States		40,078	37,262	41,115	39,956	39,575

[1] Subject to revision.

During the period of 1922 to 1926, there was very little variation in the number of carloads of cabbage shipped. The shipping peak is reached in October, which is the time when most of the main crop moves into storage. The fewest number of cars are shipped in July, with August next. During these 2 months, there is a good supply of cabbage in the market gardens near the large cities of the North and East.

TABLE 22.—CARLOT SHIPMENTS OF CABBAGE BY MONTHS, 1922–1926

Year	January	February	March	April	May	June	July	August	September	October	November	December
1922	3,346	3,422	4,185	3,831	4,010	2,253	660	1,436	3,523	7,060	3,824	2,528
1923	2,985	2,299	2,630	3,779	4,135	2,234	853	1,603	3,384	6,760	4,211	2,389
1924	4,097	3,665	4,565	3,365	3,722	2,462	1,028	1,496	3,559	6,165	4,576	2,415
1925	4,075	3,597	3,804	4,142	3,660	1,784	666	1,270	4,021	6,750	3,595	2,592
1926[1]	3,613	2,889	3,424	4,174	4,497	2,753	820	1,085	3,216	6,003	3,953	3,148

[1] Subject to revision.

STORAGE

About half of the late crop shipments are either from farms or commercial storage. Only the Danish type can be stored successfully. Farm storage of late cabbage may be in shallow pits, in furrows, or in old hotbeds. The cabbage is usually placed root upward and then covered with straw, or litter, and then earth. Cabbage is also stored in cool, well-ventilated cellars, where moderate humidity and low temperature (0°C.) can be maintained.

The cellar method of storage is probably most desirable. Dealers also place a large quantity of the Danish type of cabbage in commercial storage houses in the producing areas or in warehouses in the market centers. The storage season begins in November and continues until March. The storage houses are frost proof and equipped to give good ventilation. Rows of bins 3 to 4 feet wide are placed in tiers on each side of the house. The heads are placed in layers on each rack, and sufficient room is left between the racks for ventilation. Nearly 95 per cent of all commercially stored cabbage comes from New York and Wisconsin. Probably most of the shipments from these states after Nov. 1 are out of storage.

Kraut.—Most of the commercial supply of kraut is manufactured in the cabbage-producing areas of New York and Wisconsin. When prices are low, however, much of the domestic cabbage in the midwestern cities and in Philadelphia and Baltimore is used in kraut manufacture. When the crop is large and the prices low, kraut manufacture is stimulated; it is curtailed during periods of high prices.

CLASSIFICATION

The classification outlined below is that suggested and followed by Myers (1917) and by Myers and Gardner (1919). The varieties are classified into eight groups as follows: (1) Wakefield and Winningstadt, (2) Copenhagen Market, (3) Flat Dutch, or Drumhead, (4) Savoy, (5) Danish Ballhead, (6) Alpha, (7) Volga, and (8) Red Cabbage.

Wakefield and Winningstadt.—This group includes the varieties having pointed heads. Wakefield's are grown chiefly for the early crop. Examples are Early Jersey Wakefield, Charleston Wakefield, and Winningstadt varieties.

Copenhagen Market.—The plants in this group are of medium size and possess short stems, and the leaves are few in number and curve inward, enclosing the head loosely. The veins are numerous, especially at the tips of the leaves next to the head, where they form a characteristic network. Heads are a slightly flattened globe in shape and very solid. Examples are Copenhagen Market and Golden Acre.

Late Flat Dutch, or Drumhead.—The plants of this group are medium to large n size, and the outer leaves are large, numerous, curve inward, and enclose the head loosely. The leaves are broad and thick and petioled at the base. The veins are numerous, fine, and very pronounced; the margin is crenate, and the surface, undulate. The color is light green, with considerable dull bloom. The heads are generally large, very nearly flat, and moderately solid. The head leaves usually overlap the center. Varieties of this group are subdivided into Early, Intermediate, and Late, because there is a difference among them of several weeks in time of maturity. A few examples of the Early varieties are Early Flat Dutch and Pride of Erfurt—Midseason varieties; Succession, All Seasons, and Summer Drumhead—Late varieties; Late Flat Dutch and Autumn King.

Savoy.—This group is of limited commercial value. The foliage is dark green, much blistered, and has very little bloom. The quality is said to be excellent, and its greatest perfection is reached only after the plants have been subjected to a severe frost. Examples are the varieties Hardhead Savoy and Perfection Drumhead Savoy.

Danish Ballhead.—The Danish Ballhead group is best characterized by the variety Danish Ballhead. The mature plant is of medium size with a rather long, medium-sized stem. The outer leaves are few in number and curve somewhat inward. The base of the leaf is partly filled out, and the margin is undulate. The light-green color of the leaves is partially masked with a heavy bloom. The leaves are of fine texture and reach well past the center of the head. They are folded tightly and form a head which is very solid and of medium size. Examples are the Hollander, Danish Roundhead, and Glory of Enkhuizen varieties.

Alpha.—This group is of very little commercial importance. The plants are small, and the heads which they produce are small but solid. An example is the variety Alpha.

Volga.—The mature plants are large and have few outer leaves, which curve outward. The leaves are long, broad, and thick and have an undulated margin. The color is steel blue. The head is of medium size and a flattened globe in shape. The head leaves extend a short distance

beyond the center, thus giving the cabbage a bald appearance. The head is solid above but rather open below. The best example of this group is the variety Volga.

Red Cabbage.—This group is characterized by its purplish-red color. It is grown to only a small extent in this country and is used mainly for pickling. The heads are globe shaped, somewhat smaller than Danish Ballhead, and very solid. Examples of this group are Mammoth Rock Red and Danish Red.

Types.—The market supply of cabbage is usually divided into two groups, or classes, known as (1) Early, or Southern, and (2) Late, Main crop, Northern, or Storage. Early cabbage is harvested from January to July and may be either first-crop, planted in December or later and harvested early in the spring or second-crop cabbage, which is planted in the fall and harvested in the winter. The pointed varieties, such as Winningstadt, Early Jersey Wakefield, and Charleston Wakefield, constitute the bulk of the cabbage grown for early shipment. These varieties are favored because they mature early, are of convenient size for family requirements, and are easily packed. Late, or main-crop, cabbage is harvested from July to December. There are two types—Domestic, which is flat or roundish in shape and of which the variety Succession is a good example, and Danish, which has hard, globe- or oval-shaped heads and of which the variety Danish Ballhead is a good example. The Domestic type does not keep well in storage, and it is the kind generally used for kraut. The Danish is a good keeper, and therefore most of the storage cabbage is of this type.

Breeding

The general method used for breeding cabbage has been to set together a number of the plants which are most typical of the variety; but when this method is used, there is a considerable amount of crossing. The most rapid improvement will be made when selfing is followed, in order to isolate pure lines. Some of this work has been under way for a number of years in this country and in Europe. The main drawback to the method seems to be the large amount of self-sterility encountered when the plants are selfed under bags or cages. The improvement made with this crop will depend largely upon the success obtained in isolating plants which have a high degree of self-fertility.

By selfing for three successive generations, Walker (1926) established a line which is apparently homozygous for resistance to the yellows organism. Individuals homozygous for susceptibility were also obtained. The F_1 hybrids from crosses between resistant and susceptible individuals are nearly all disease free. In the F_2, a ratio of approximately three resistant plants to one diseased one was obtained when they were grown on infested soil.

Detjen (1926), working in Delaware, found that the factor for heading is dominant over that for non-heading. In one case, when a heading strain of cabbage was crossed with a non-heading, 218 out of 224 plants in the F_1 formed solid heads, and six were in various stages of head formation at the time the records were taken. The progeny of the F_1 plants gave approximately the expected ratio of three heading to one non-heading. When red and green varieties are crossed, Kristofferson (1924) states that red is dominant in the F_1 while in the F_2, a mono-hybrid segregation is obtained. When he crossed cabbage and broccoli, the F_1 hybrids had shorter and broader leaves than the broccoli. Curds did not develop, but there was a tendency to form a head at the top of the stem. The F_1 plants of a cross between Brussels sprouts and cabbage resembles the former to a marked extent. Well-developed heads were present in the axils of the leaves as well as a fair-sized head at the apex. The petioles were shorter and the blades broader than in Brussels sprouts.

Cabbage-seed Growing

The greater portion of the cabbage seed used in the United States is probably imported from Denmark. Walker (1924) states that there are two ways of handling the cabbage seed crop in Denmark, and these are known as the (1) transplanting and (2) the direct sowing method.

Transplanting Method.—In this method, the seed is sown in beds sometime in May. Within 6 to 8 weeks, the plants are set in the field; they are spaced 18 to 22 inches in rows about 2½ feet apart. The heads are sufficiently mature by late October to make careful rogueing possible. The loose outer leaves of the plants are removed, and the head is cut with about 4 inches of the stem remaining. A furrow is plowed, and the plants are set upright 18 to 24 inches apart in trenches about 4 feet apart and covered so that the top of the head is only slightly exposed. The plants then develop a new root system. The heads are covered with soil during the winter. In the spring, the soil is removed and the head cut open, so that the central stem can elongate. This system is the one used for the stock seed and, to a certain extent, for the trade seed. Stock seed of each variety is produced from heads which are selected with great care as to uniformity and type. It is very important that the plants for stock seed be selected rigidly, especially when the trade seed is not rogued.

Direct-sowing Method.—In this method, the seed is drilled in rows about 4 feet apart in the field. Seed is usually sown in late June or July. When the seedlings have two to four leaves, they are thinned 15 to 20 inches apart in the row. By October, the plants are only about half grown, and the heads are not formed. Rigid rogueing is not possible when the latter method is followed. This system is cheaper and less complicated than the transplanting method and is the one used almost

entirely for the early and medium varieties. The plants are not protected during the winter. In the spring, flower shoots are formed.

A considerable amount of cabbage seed is produced in the United States and is grown on Long Island and in the Puget Sound district. In the latter district, the seeds are sown about the middle of May. The plants are set in the field about the first of July, 16 inches apart in rows 3 feet apart. In October the fields are rogued and the selected heads are removed to the seed fields. The plants are set in rows 6 feet apart. They are covered with soil about the middle of November and are left covered until about the first of March. Just before they are in bloom, stakes are set in the rows about 6 feet apart. A heavy twine is strung along both sides of the row and fastened to the stakes about 2 feet from the ground. This prevents the branches from breaking off or from resting on the ground. Before the stalks are cut, late in July, a deep furrow is plowed between the rows and stakes laid across it. When the pods turn brown, the plants are cut and laid on these stakes. The furrow beneath the pile facilitates aeration. The seeds are ready to thresh in about 2 weeks from time of cutting. The seed plants are hauled to the threshing machines in canvas-lined sleds. After threshing, the seed is placed in burlap sacks. The sacks are about half filled, and these are turned every day for 2 weeks to cure the seed thoroughly.

On Long Island, the seed is usually sown in open seed beds in June. When of sufficient size, the plants are set about 15 inches apart in rows 3 feet apart. The object is to get a fully formed head that is not solid. The selected plants are trenched and covered during the winter. In the spring the plants are set 3 by 4 feet. When pods are brown in color, the stalks are cut and laid on the ground to dry. When sufficiently dry, the threshing is done on a canvas with a flail. The average yield is about 300 pounds per acre.

Diseases

Club root (*Plasmodiophora brassicae*).—The club-root of cabbage has been known in Europe for a century or more and at present occurs in England, Holland, Russia, and other European countries. It is reported as being present in New Zealand and Australia and is probably present in this country in most of the states east of the Mississippi River. The plants are often attacked in the seed bed, taking on a stunted, sickly appearance. Diseased plants seldom grow to maturity. Kunkel (1918) states that cabbage plants of all ages up to 1 year are susceptible to club-root. Old plants are almost as susceptible as young ones, provided they are growing. Harter and Jones (1918) state that during the early stages of infection, foliage wilts in the sunshine even in the presence of plenty of moisture. The plant recovers, however, toward evening or during cloudy

weather. The roots develop swellings similar to but larger than those caused by the nematode.

Kunkel (1918) has shown that the host cells may become affected (1) by direct penetration of the organism and (2) by division of the host cells. The infection by direct penetration occurs in four stages: (1) primary infection of cortical tissues and penetration to the cambium, (2) infection of the cambium in all directions from the point of original penetration, (3) passage of the plasmodia from the cambium into the cortex and xylem region, and (4) infection of the medullary rays. Kunkel states that the infection of a given cell may be either permanent or temporary. If it is temporary, it has no noticeable effect on the cell. If it is permanent, it stimulates the cell to abnormal growth and division. The growth stimulus is diffuse, *i.e.* it acts on the uninfected cells of the diseased tissues as well as on the infected ones. The stimulus seems to travel in advance of the infection.

Control.—Various authors recommend the following methods of control: (1) Grow seedlings in disease-free soil and, if buying plants for transplanting, be sure that they are not infected; (2) the club-root organism thrives best in an acid soil; lime should therefore be applied to acid soils several months before the crop is to be planted; (3) diseased plants should be entirely destroyed by burning; (4) a long rotation without other cruciferous crops should be practiced; (5) fields should be kept free from all cruciferous weeds; (6) wet land should be drained to facilitate aeration.

Cabbage Yellows (*Fusarium conglutinens*).—The yellows disease is rather widespread in the eastern United States, being most serious in the older and more intensive cabbage-growing sections from Iowa and southern Wisconsin across Illinois, Indiana, Ohio, Pennsylvania, Maryland, Delaware, and New Jersey. The disease is less prevalent as one goes northward, and it is not very serious where cabbage is grown as a winter or early-spring crop. It seems to be most prevalent where high soil temperatures exist during the early stages of development of the plant. The disease is reported, however, to occur near Mobile, Alabama, in central Mississippi, in the Greeley district of Colorado, and in Kansas.

Cabbage yellows has received considerable attention from L. R. Jones and his colleagues at the University of Wisconsin. It is caused by a soil fungus which invades the roots either in the seed bed or in the field. Infected plants are stunted, and the foliage turns to a pale yellow. The fibrous roots are probably the first organs to be invaded; and from these, the fungus passes to the stem, showing first in the vascular bundles. These appear water-soaked at first, then darken, and finally become a brownish black in the later stages, while the cortical tissues overlying them gradually die and collapse. The fungus grows into the vascular system of the upper portion of the stem and also of the leaves. The invaded plants begin early to shed their lower leaves. Death may result in the

more severe cases within a week or so after transplanting, although diseased plants may exist for a month or more, then succumb; a few, less severely attacked, live throughout the summer but rarely form heads.

Tisdale (1923) found that cabbage yellows develops in seedlings growing in infected soil at soil temperatures ranging from 17 to 35°C. On naturally infested soil, the disease appears first and develops most rapidly in both resistant and susceptible strains at 26 to 29°C. Resistance to yellows becomes more pronounced with increasing age of the plant. Young seedlings of the resistant strains develop a relatively high percentage of yellows when started in infected soil at high temperatures, whereas plants grown for 30 days or more in non-infested soil or even infected soil below 17°C., when transferred to sick soil at high temperatures, develop only a low percentage of yellows and then usually only in an incipient form. This is significant, in that it indicates that if plants are to be set in infested soil, they should be started in a non-infested seed bed when the weather is cool. Occurrence of yellows is also closely correlated with soil moisture. Tisdale (1923) found that the yellows developed more rapidly and destructively in susceptible plants when the moisture was held at 15 per cent than when held at 19, 23, or 26 per cent in a soil the moisture holding capacity of which was 46 per cent.

The causal organism, when once introduced, seems to be able to persist indefinitely in favorable soils, even when cabbage is not grown.

It was early recognized that the best method of control was by the selection of resistant strains. This was accomplished by selecting the resistant or surviving plants in badly infected fields. The work conducted in Wisconsin, Maryland, Iowa, and other states has shown that it is possible to secure Fusarium-resistant strains within almost all of the standard varieties. Furthermore, by careful selection, resistance may be combined with other desirable qualities. The practice generally followed is to grow the selected head in isolation and thus secure inbred or selfed seed. The desirable plants from the inbred seed are then grown in mass culture. In order to maintain resistant stocks with certainty, it is always best to grow on infected soil the plants which are to be used for seed production.

From work done by Tims (1926), it appears that resistance of certain strains, or varieties, of cabbage is not because of differences in morphology or cell-sap acidity. Tims suggests that there may be an S-containing compound present in yellows-resistant plants in sufficient amounts to account, in part, at least, for the resistance factor. In a later paper (1926a), this author states that "The difference between the resistant and susceptible strains seems to lie in the ability of the former to prevent the developmnet of the fungus after it has once gained access to the tissues."

Black Rot (*Bacterium campestris*).—Black rot occurs in almost all states east of the Mississippi River and from several west of it, especially

Iowa and Nebraska. In 1908 it was reported from the state of Washington, but with a few possible exceptions it is of rare occurrence in the Rocky Mountain and Pacific coast states. The causal organism is a soil-infesting bacterium. Infection takes place either through the leaves or the roots. In the latter case, the bacteria soon spread through the whole plant. Most of the infection takes place through the leaf margins, the bacteria being carried by insects or dust particles.

This disease may appear in the plant at any stage of growth. The chief symptoms are dwarfing, or one-sided growth, of the heads or, if the disease is very severe and has begun early in the season, entire absence of heads and, in extreme cases, death of the plant. Occasionally the heads rot and fall off. The soft, bad-smelling rot which accompanies black rot is due to the entrance of other organisms. If the stumps of affected plants are broken or cut across, a brown or black ring will be observed, corresponding to the woody part of the stem. In severe cases, this blackening may be easily traced upward into the center of the head and is generally worse on one side. In the leaves, the symptoms usually begin at the margins and consist in a yellowing of all the affected parts except the veins, which become decidedly brown or black. The leaves look as if they had burnt edges. From the margin of the leaf, the progress of the disease is inward and downward toward the stem. It usually enters the latter through the leaves. Subsequently, the disease passes out again from the infected stem into healthy leaves and up into the center of the head. Leaves attacked in this manner fall prematurely one after another, leaving in bad cases a more or less elongated stem covered with leaf scars and crowned with a tuft of small leaves. If the disease has entered the stem only on one side, that side is dwarfed and the head becomes one-sided.

Control.—The following methods will help to control black rot:

Seed Treatment.—As the bacteria causing black rot are carried on the seed, it is advisable to disinfect the seeds before planting. Soaking in a water solution of mercuric chloride (1:1000) for 30 minutes followed by rinsing and drying is effective.

Crop Rotation.—Cabbage should be grown in a rotation with other non-cruciferous crops and should not appear in the rotation more than once in 4 or 5 years where there is danger of infection with black rot.

Clean Seed Bed.—Plants should be grown on disease-free soil, or the soil should be sterilized by use of steam or formaldehyde.

Sanitation.—Diseased plants should be destroyed by burning as soon as they are detected. Insects should be kept under control, as they may carry the organism from the infected to the non-infected plants. Diseased plants should not be fed to stock.

Black Leg (*Phoma lingam*).—Black leg is a destructive disease affecting cabbage and other crucifers. It occurs in many of the cabbage-

producing areas east of the Rocky Mountains but is of minor importance in the Pacific coast states.

Black leg may be carried with the seed and persists in the soil. The first infections commonly take place in the seed bed, more often in the stems than on the leaves. Maggot or other insect injuries favor infection; it occurs, however, readily in the absence of wounds.

The earliest symptoms may appear in the seed bed. Infection frequently occurs on the stem near the surface of the ground, causing dark, sunken or irregular areas. From these spots the disease spreads, gradually girdling the stem, so that the plant wilts and perishes. Wilting of the entire plant is characteristic of the advanced stages of black leg, and the leaves adhere to the stem, instead of falling off as in yellows. Frequently, diseased plants show a purpling of the leaves even before any wilting occurs. Often the disease appears as dead spots on the older leaves or leaf stalks; and with seed plants, a spotting of the flowering branches and seed pods is common. In its advanced stage, the dead areas are covered with minute raised black specks, which are the fruiting bodies (pycnidia) containing the spores.

The development of the disease varies with the temperature and moisture, but, as a rule, the parasite kills and discolors spots on stems or leaves, and within 2 weeks these are usually thickly studded with numerous pycnidia. The spores are distributed by water, insects, and other agencies to healthy plants. Wet weather or flooding favors the rapid spread of the disease, while the presence of maggots increases its destructiveness.

Control.—Black leg may be controlled as follows:

Sanitation.—The spores of the black-leg fungus live over winter in the diseased remains of the crop. It is therefore advisable as far as possible to destroy the crop refuse. If plants are grown in hotbeds or cold frames, new soil should be used or else the old soil should be sterilized with steam or formaldehyde.

Crop Rotation.—New seed beds should be used when the plants are grown in the open. Where the disease has occurred in the field, cruciferous crops should not be planted in it for at least 3 years.

Seed Treatment.—As the disease may be carried on the seed, Walker (1924) recommends immersing it in water for 30 minutes at a temperature of 50°C. The hot-water treatment will control black leg, but, as it reduces the percentage of germination somewhat, it should be used with caution, and preliminary tests should be made on each lot before planting. After treating, the seed should be cooled and then dried as rapidly as possible. Clayton (1924) found that cauliflower plants treated in the seed bed three times with corrosive sublimate 1:1,000, just as for the control of cabbage root-maggot, effectively checked black leg.

INSECTS

Aphis (*Aphis brassicae*).—The cabbage aphis attacks cabbage and related brassicas. It occurs in all parts of the United States and is found living upon the wild and cultivated brassicas.

The true females appear in the autumn, are fertilized by the males, and deposit the eggs on the food plant. Here the eggs remain until the following spring, when they hatch into the stem mothers. The latter give birth to wingless agamic females that mature in 10 to 14 days and in turn give birth to many young. This method of reproduction goes on throughout the season, varied now and then by the appearance of winged agamic females that fly to other plants. The winged agamic females are apparently produced only when the plant becomes abnormally crowded or when it loses its vitality for any reason and begins to droop and die. The winged females give birth to the true wingless females in the autumn, thus completing the seasonal history. In the South, the weather conditions may be such that aphis can live throughout the winter without the production of males and females and winter eggs.

The aphis colonies are usually found on the underside of the older leaves and on the young, succulent, inner leaves. When the colonies appear on the edges of the leaf, they cause it to curl inward. They lower the vitality of the plant by sucking out the juice.

The cabbage aphis is kept under control to a certain extent by numerous parasites, which increase their activity as the weather becomes warm, also by predaceous insects, such as the ladybird beetles and syrphus-fly larvae. Many aphis are destroyed by hard rains.

Control.—There are three good ways in which to control aphis:

Spraying.—Cabbage aphis may be controlled with a liquid spray of nicotine sulphate, fish-oil soap, and water. When using a liquid spray, an effort should be made to have the spray reach both sides of the leaves. The aphis must be hit with the spray for the latter to be effective. As a rule, it is rather difficult to obtain a perfect kill with liquid sprays, because the lice are usually either on the underside of the leaves, protected by the incurving foliage or by rolled edges.

Dusting.—Dusts containing nicotine sulphate are being used more and more for the control of this insect. The dust can be blown into and about the plant so that the fumes of nicotine come into contact with every part of it. A dust containing 5 per cent of 40 per cent nicotine sulphate gives the most satisfactory and at the same time the most economical control. A formula for making this dust is 95 pounds of hydrated lime plus 5 pounds of 40 per cent nicotine sulphate. On cabbage less than half grown, about 30 pounds of dust for each acre will be required; and for more mature plants, about 50 pounds. When dusting large plant beds in the field with power dusters, long trailers should be attached in order to hold the dust close to the ground and about the plants.

Dipping Plants.—It is often advisable at time of transplanting to dip the plants in a soap-nicotine-sulphate solution to prevent carrying lice into the field from the seed bed. The plants are dipped and then placed in tight boxes until time of transplanting.

Sanitation.—As many of the wild brassicas and other native crucifers are hosts to the cabbage aphis, they should be kept out of the fields and waste places.

Cabbage Worm (*Pontia rapae*).—The common cabbage worm is probably present in almost every part of the United States. The damage is done by the larvae consuming the leaves. Wilson (1919) states that considerable damage is done by the larvae's eating the terminal portion, or "friction cap," of the inner leaves. The early head leaves overlap and form a sort of enclosure within which the inner leaves develop into a compact mass. If the larvae eat the terminal part of the first head leaves, the enclosure is not formed, and the head leaves continue to grow upward and outward. Damage to the mature plant is caused by the larvae eating the outer leaves and tunneling into the heads.

The eggs are deposited singly on either surface of the leaf but generally on the undersurface. They are always deposited so that they stand at right angles to the leaf surface and can be seen with the naked eye. When first deposited, they are light greenish-yellow in color, later turning to a dark lemon-yellow. The eggs hatch in from 3 to 10 days, depending upon the temperature. When the larva is hatched, it first consumes its shell and then starts feeding on the plant tissue. The larva molts five times and, when mature, is velvety green and about 1¼ inches long. It becomes full grown in from 10 days to 2 weeks. The chrysalis of the summer generation is greenish to greenish grey in color, while that overwintering is more of an ashen grey. In summer, the adults emerge in 1 to 2 weeks. The general color of the adult is white with black markings near the tip of the forewings. In the northern United States there are normally three generations each year; while in the extreme South, there are probably five or six. There are a number of parasites that attack the cabbage worm, one of the most important being a small, wasplike braconid fly, which was imported from England in 1883. The small chalcis fly is also a very important parasite. Wasps as well as various bugs, spiders, and birds prey upon the larvae.

Control.—To control cabbage worm, use the following methods:

Spraying and Dusting.—Arsenicals give the best control. Some growers hesitate to apply lead arsenate or other arsenical sprays, because of the danger to the consumer. Arsenicals, however, can be used with very little danger of poisoning, as the head grows from the inside and all of the head leaves that the spray reaches are discarded in the field at time of trimming or by the consumer in preparation for the table. Arsenicals may be applied in solution or as a dust. A good spray is 1½ pounds of

powdered lead arsenate, 1 pound of soap, and 50 gallons of water. Dusting with a mixture of 1 pound of powdered lead arsenate and 8 to 10 pounds of air-slaked lime, or gypsum, will give excellent control. The dust may be applied with a power duster or with a hand duster by shaking through a burlap sack or tin can perforated at one end. It is best to apply the dust while the dew is on the plants.

Sanitation.—As the chrysalids may pass the winter on the old cabbage stumps and other refuse in the field, the plants should be destroyed and the field plowed as soon as possible after the crop has been removed.

Methods for controlling the cabbage looper are the same as those described for cabbage worm.

Harlequin Cabbage Bug (*Murgantia histrionica*).—According to Chittenden (1920), the harlequin cabbage bug, is a native of Mexico and Central America. At the present time, this pest is destructive throughout the South. Occasionally it becomes destructive as far north as New Jersey and Long Island, and California is not free from its devastations. Both the adult and the young suck the juice from the leaves of the cabbage and other cruciferous plants. The affected parts take on a yellow color, then wither and die.

The bugs are shining back or deep blue marked with brilliant orange or red. They are about ½ inch long and flattened. The eggs, usually about twelve in a cluster, are laid in double rows on end; they are barrel shaped and white, with two black bands, and they are usually found on the underside of the leaves. There are five nymphal stages.

In the extreme South, the harlequin cabbage bug is active throughout the year. All stages of infestation have been found in abundance in southern Texas in January and February. Near the District of Columbia, however, winter is passed chiefly in the adult stage. The bugs seek concealment in tufts of grass, in cabbage stumps, and under other rubbish left in the field. Probably the nymphs perish when the weather becomes sufficiently severe in the fall. Many adults perish during the cold winter months in the northern range of this insect's activity. The length of the different stages is determined by the temperature. The summer generations are much shorter both in the North and in the South than those of the spring and fall. It may require 4 to 10 days for the eggs to hatch and 3 to 9 weeks for the nymphs to mature.

Control.—In order to obtain good control, preventive measures are necessary, as it is rather difficult to control the insect with ordinary contact insecticides.

Hand Methods.—Very good control may be had by hand picking the adults as they appear in the field. The egg masses should also be destroyed.

Trap Crops.—Where the insect is abundant and there is danger of severe infestation, trap crops such as kale or other crucifers, should be

planted preceding the commercial crop. These crops attract the insect, and the latter may be destroyed by spraying with pure kerosene. Chittenden (1920) states that this insect is especially fond of horse-radish. This is a perennial and serves as a natural trap crop throughout the entire growing season.

Clean Culture.—Throughout the year all weeds, especially crucifers, should be destroyed as they serve as a source of food and as a means of protection during the winter. All refuse should be burned or plowed under deeply in the fall, especially in the more northern range of the insect's habitation.

Contact Insecticides.—The nymphs can be killed by use of a 10 per cent solution of kerosene emulsion or a whale-oil-soap solution consisting of 2 pounds of soap to 4 gallons of water. These sprays are not effective against the adults.

SECTION B. CAULIFLOWER AND BROCCOLI

History.—It seems that the improved varieties of broccoli and cauliflower are of comparatively recent origin. The sprouting broccolis, which have a more or less open head, were probably the forerunners of the compact-heading broccolis, and the latter probably gave rise to our present varieties of cauliflower. From about 1700 to the present time there has been a slow but steady improvement in size and quality. The English and Danish gardeners have been mainly responsible for the great improvements made during the last 100 years.

Plant Characteristics

Leaves.—The leaves of the cauliflower are usually longer and narrower than those of cabbage, although in some of the large varieties of broccoli they may be 15 inches wide and 3 feet long. The first leaves are petiolate; the later, decurrent, or sessile, long-oblong, or elliptic. The small inner leaves are at first incurving and protect the curd for a time.

Inflorescence.—The edible portion, or curd, terminates the main stem. According to Coupin (1923), it is made up of numerous, much-divided, hypertrophied branches. At the time when the head is in its prime for cutting, there is no trace of floral organs. The floral primordia appear after the curd is past its prime for harvesting. Later, the branches elongate into flowering stalks, causing the head to spread, but many of the smaller branches abort. The flower, fruit, and seed characters are the same as described for cabbage.

Climate and Soil Requirements

Temperature and Moisture.—Cauliflower attains its most perfect development in those areas where the temperature during the latter part

of the growing period is cool and uniform and where fairly moist conditions prevail. Hence, the growing of cauliflower is largely localized in areas where the climate is tempered by ocean breezes, as in the coastal counties of California and Oregon and on Long Island. Temperatures below the optimum delay maturity, reduce the size, and consequently lower the yield per acre. Extremely low temperatures during the early growth period of the plant may cause it to "button," or head prematurely. Low humidity and wind storms are injurious. Extremely high temperatures during the time when the curds are maturing may cause them to become yellow, ricey, fuzzy, or leafy and may cause such rapid growth of the curd

FIG. 28.—Open flower of broccoli; 2 petals removed.

that it is almost impossible to harvest in the best stage of development, especially when large acreages are being handled. Early varieties, however, are often grown successfully as spring or fall crops, in inland regions.

There should always be a sufficient supply of moisture in the soil to insure a continuous and steady growth. Uniformly distributed rainfall or well-regulated irrigation is necessary for the successful production of this crop.

Soil Preferences.—Cauliflower may be grown very successfully on a variety of soil types, but the soil should be fertile, of good physical condition, retentive of moisture, and well drained. Where a number of different soil types are available, the medium and heavy soils should be used for varieties which mature in the fall and spring, as they are cool and retain moisture well. When the crop is brought to maturity during the rainy season, as is the case with part of the California crop, it should

be planted in sandy or silty soils so that harvesting can be done without getting the soil into a poor physical condition. Soils of very light texture, however, should never be used for cauliflower production unless they are abundantly supplied with organic matter.

Cultural Methods

Growing Plants.—Cauliflower plants are grown in the same manner as described for cabbage. In California, most of the plants are grown in open beds. A sandy-loam soil of medium fertility is best. Two types of seed beds are used, the sunken bed, or panel, and the raised seed bed. Where the soil is light and porous and not subject to packing, sunken seed beds are generally used. These are of any desired length, 12 to 16 feet wide, with small dikes or levees on each side to facilitate irrigation by flooding. Sunken beds have a minimum of surface exposed and hence dry out more slowly than raised beds. On the heavier soil types, the raised bed has been found to be more satisfactory. These are similar to the ones used for the growing of lettuce under irrigation. They are usually about 6 inches high and approximately 18 inches wide, with furrows between. Each bed has two rows of plants which are spaced 10 to 12 inches apart. To sow 1 acre of seed bed, 12 to 15 pounds of seed are sufficient, and it should produce plants sufficient for 25 acres. Plants which have been stunted by remaining in the seed bed too long should not be used, as they may head prematurely. Care should be exercised to develop healthy, stocky plants.

Transplanting.—When grown under irrigation the plants are usually set in the bottom or side of the furrow. In soils of sandy texture, planting is done on the furrow bottom. Plants are set so that they will not be submerged by the irrigation which follows. They are usually spaced about 24 to 30 inches in rows 3 feet apart, depending upon the variety. Crowding should be avoided, as it has a tendency to reduce the size of the curd.

Manuring.—As with other truck crops, there is a considerable difference of opinion among growers as to the value of the various fertilizers. Many of the most successful growers use large amounts of barnyard manure. Cauliflower growing and dairying make a good combination, as an abundant supply of manure can be obtained, and a good system of crop rotation can be established. In certain sections, the productivity of the soil must be maintained by the use of commercial fertilizers. In general, the growers have found that it is lack of N which usually limits the growth of the cauliflower plant. Formerly, the Chinese growers in California used large amounts of fish meal; other sources of organic or inorganic N are now being used to get the desired growth response.

Blanching.—The market demand is for a pure white curd. Varieties such as Snowball have a small amount of foliage, which does not cover the

curd or protect it from the sun. Exposed curds develop a brown pigment that is very objectionable. To prevent discoloration, the outer leaves must be gathered together and tied, while the small, inner leaves still protect the curd. A different kind or color of tying material may be used each day the field is gone over, so that at the time of harvest, the plants which have been tied the longest may be identified. The method sometimes used of breaking the leaves over the curd is not satisfactory, as the leaves may be displaced by the wind, and if they start to decay, they cause a yellowing of the curd. The length of time necessary for the development of the curd to a marketable condition after tying depends largely upon the temperature. During warm weather, the curd may be ready to harvest in 2 or 3 days, but during the cooler part of the year it may not be ready for 2 weeks, or longer. The curds of broccoli and some varieties of cauliflower are sufficiently protected until ready for harvest so do not need to be tied.

Harvesting.—The curds do not develop uniformly in all plants; hence, several cuttings are necessary. The heads are cut, trimmed, and thrown into a high-wheeled cart and hauled to the ends of the rows, where they are transferred to wagons, or trucks, to be hauled to the packing shed. The axles of the cauliflower carts are bent, thus elevating the bed so that it will clear the top of the standing plants. The bed of the cart works on a hinge to facilitate the unloading.

A sufficient number of jacket leaves are left on at time of harvest to give good protection. Many growers cut the stem to the desired length in the field so that it will not need further trimming at time of packing. The tips of the leaves may be cut back at time of harvest or they may be left intact until the crate is packed. The fields are gone over every few days in order to cut the curds before they become overmature. It is imperative that the curds be cut while they are still compact, especially for long-distance shipment. There is very little danger of cutting the curds before they have reached the proper size. If the plants have not made a good growth, the curds will not grow large regardless of how long they remain in the field. It is generally considered a better policy to disregard the size feature entirely and consider only the condition of the curd itself.

When growing for shipment, it is necessary to keep in mind how the curd will appear by the time it reaches the market. Appearance is an important factor in the sale of any commodity, and if an overmature head gets into the crate, it will probably spoil the appearance of the entire crate. Overmature curds are very conspicuous, because the advanced growth spreads the leaves and exposes the curd to a greater extent than when in the best harvesting stage. Younger curds are more concealed in their jacket leaves and are therefore less conspicuous.

Cauliflower matures quickly in warm weather. Unless such periods are anticipated and additional labor provided, a large portion of the crop may be lost. If a part of the field has become overmature, it is best to accept the loss and continue to cut only the desirable heads rather than to attempt to harvest those that have passed by their best marketable condition. Occasionally during a rush period the cauliflower heads are cut and left inverted in the field for a short time; this checks the growth and prevents losses which might otherwise occur.

Defects

Over-maturity.—The stage of maturity of the curd affects very markedly its carrying qualities. The longer the curds are left in the

Fig. 29.—Cauliflower head allowed to become over-mature.

fields after they are ready to cut, the sooner they appear wilted after harvest. If the curds are spread, by the time they reach the markets they are almost unsalable; therefore, every effort should be made at time of cutting and again at time of packing to discard all curds of this type. If the curd is slightly spread at time of packing, this condition is usually much more pronounced by the time it reaches its destination.

Riciness.—Riciness is caused by the elongation of the peduncles which bear the individual flower buds. This condition causes a granular appearance of the curd, and it is not as compact as it should be. While a ricey curd is not as objectionable as one that is badly spread, nevertheless, it suffers some differential in price. This condition may be prevented to some extent by the selection of good-quality seed and growing

the crop under the most favorable climatic conditions. It is usually more common when the crop matures during exceptionally warm weather. It may also be brought about occasionally by allowing the curds to become slightly overmature. Curds may be badly spread, however, without being ricey.

Fuzziness.—When the flower pedicels elongate, the curd appears velvety, or fuzzy. This condition is most prevalent when the crop grows under unfavorable conditions. There is, however, a considerable dif-

FIG. 30.—Ricey cauliflower head.

ference between varieties and strains in the tendency to become fuzzy prematurely. The condition may also be brought about by allowing the heads to become slightly overmature. It may be prevented by observing the same precautions that prevent riciness.

Leafy Heads.—This is a defect in which small green leaves appear between the segments of the curd. Heads of this type are undesirable and, if possessing many leaflets, should be discarded. This condition is generally assumed to be due to poor seed, but even the best strains may develop leafy curds when the growing conditions have not been

favorable. Clayton also mentions leafy curds as one of the symptoms of whiptail.

Yellow Leaf.—If subject to high temperature after cutting, the jacket leaves will turn yellow and drop off during transit or after reaching destination. Tests by Weimer (1926) showed that the rate of yellowing varied with the temperature to which the curds were exposed. After one week at 7°C., from three to six of the outer leaves were yellow and loose. In 2 weeks, or less, all of the leaves dropped at this temperature.

Fig. 31.—Leafy cauliflower head.

At 5°C., the yellowing was slower, while at 0°C., yellowing had just begun at the end of a month.

Insect Injury.—Injury by worms reduces the salability of the curds. If worms are present in the crate, they leave on the white curd a green excresence which destroys its salability and may cause condemnation of the entire lot by the inspector. The presence of aphis on the leaves at time of packing is also objectionable, as they will migrate to the top and between the branches of the curd during transit.

Marketing

Grading.—Cauliflower is inherently more subject to deterioration in transit than are many other vegetable crops. This fact makes it necessary to practice rigid grading in order that the product can be placed upon distant markets in good condition. Since much of the cauliflower shipped is sold on consignment, the price received is determined entirely by the appearance and quality of the pack.

Packing.—Most of the cauliflower for shipment is packed in single-layer, "pony," crates or flats. The curds are set erect in the crate, the foliage is trimmed to a bulge, and the three narrow slats are nailed across the top. When placed in the car, the crates are inverted so that the melting ice water will trickle down over the leaves.

Loading.—The main system now used in the loading of cars is known as the "pigeonhole method." By this system, 480 pony crates are placed in a car; the third and fifth layers from the bottom are only four crates wide, and between the crates there are placed 10- to 20-pound pieces of ice. Braces are nailed across each tier of crates to prevent them from moving about in the car. Ice is placed between the crates, on top of the load, and in the bunkers. The ice on top of the crates is usually left in large blocks weighing from 30 to 40 pounds. The amount of ice used at time of loading varies with the season of the year. Under long-distance shipment, it is thought by some that the product reaches the eastern markets in a better condition when the pigeonhole method of loading is used than when the shipments are made "solid pack."

Production Areas of the United States.—Most of the cauliflower grown for shipment is produced in California, New York, Oregon, and Colorado. New York State has always grown a large amount of cauliflower, but, as shown in Table 23, Oregon and Colorado have come to the front within the last few years. Cauliflower production has had a great stimulus in Colorado since 1922.

Shipping Seasons.—California is by far the heaviest producer. In 1925, 73 per cent of the carlot shipments had their origin in California. The bulk of the California crop moves during the months of October to April, inclusive. From the northern district the bulk of the crop is shipped from November to March. From the southern district the crop moves mainly from October to May. Most of the crop from the latter district, however, is shipped during November, December, January, and February. In the central district, the crop moves from November to May, with the greatest shipments during December, January, February, and March. The two states that compete with the California product on the eastern markets are Oregon and New York. The Oregon spring crop moves during February, March, and April, while the fall crop is shipped mainly during October and November. The New York crop moves from August to December and competes with the fall shipments from California, Colorado, and Oregon. The markets of the country are usually very well supplied with cauliflower from September to March. Districts which can grow cauliflower after March will no doubt find a ready market. The following tables give the shipping season and the carlot shipments of cauliflower by months for the United States and California, respectively.

TABLE 23.—CARLOT SHIPMENTS AND SHIPPING SEASONS OF CAULIFLOWER BY STATES, 1921–1926

(*Bureau of Agricultural Economics*)

	Shipping season	1921	1922	1923	1924	1925	1926[1]
California	October to May	3,203	3,137	3,575	3,150	3,850	3,784
Colorado	July to November	2	4	101	29	191	199
Michigan	October to November	4	1	34	66		
Minnesota	August to November	5	3	18	6	21	13
New Mexico	August to November	.....	.....	8	35	18	
New York	August to December	471	683	653	696	834	1,019
Oregon	February to April, September to December	83	133	277	415	333	1,436
Virginia	May to June	14	15	13	37	12	30
Total for entire country		3,895	3,391	4,695	4,466	5,280	6,558

[1] Subject to revision.

TABLE 24.—CARLOT SHIPMENTS OF CAULIFLOWER BY MONTHS FOR UNITED STATES, 1921–1926

Year	January	February	March	April	May	June	July	August	September	October	November	December
1921	654	516	782	7	22	2	...	13	171	493	631	604
1922	580	544	1,046	219	27	17	...	22	150	320	283	783
1923	1,142	698	965	191	34	20	7	41	123	464	621	389
1924	623	975	777	161	108	16	1	65	157	477	621	485
1925	838	822	484	215	96	6	20	270	521	531	479	1,006
1926[1]	881	1,094	1,604	245	57	23	6	103	207	1,005	825	508

[1] Subject to revision.

TABLE 25.—CARLOT SHIPMENTS OF CAULIFLOWER BY MONTHS FOR CALIFORNIA, 1921–1926

Year	January	February	March	April	May	June	July	August	September	October	November	December
1921	649	508	718	4	7	2	..	13	44	185	476	597
1922	580	544	1,037	116	12	16	..	4	11	14	65	738
1923	1,141	698	802	92	22	17	7	5	8	33	443	307
1924	618	872	591	83	81	6	..	17	1	50	375	456
1925	838	818	429	213	84	5	4	5	4	127	348	977
1926[1]	877	897	840	235	44	..	..	6	1	45	363	476

[1] Subject to revision.

These tables give a good indication of the amount shipped at different seasons of the year. If the fall happens to be warm and moist, the crop usually starts moving much earlier than if the weather is cold and dry. If the weather during midwinter and late winter is warm, the crop matures much more rapidly and there are fewer late shipments than during a cool spring.

Varieties

There are two types of broccoli—the sprouting and the heading. The sprouting broccoli (Purple Sprouting, White Sprouting) do not produce a solid head but are grown for the thickened flower branches which arise from the axils of the upper leaves and from the terminal end of the main axis. The cauliflower broccolis (St. Valentine, Black Broccoli) are similar to cauliflower in their method of heading. Both types of broccoli have a longer growth period than cauliflower, and, as far as is known, the heads are always produced the year following that in which it is sown. The plants of broccoli usually grow to a large size, are hardy, and have a good covering of inner leaves which protect the curd from frost and sun. There is very little difference between the true cauliflower and the cauliflower broccoli. In the former, the growing season is usually shorter, and some varieties, especially the Dwarf, do not have the curds so well protected by the inner leaves. Examples of early-cauliflower varieties are Snowball and Dwarf Erfurt; later-maturing varieties are Dry Weather, Pearl, and Veitch's Autumn Giant.

Seed Growing

A considerable amount of cauliflower seed is produced by the commercial cauliflower growers of California. One method of growing seed, now commonly used, is to set aside several rows in one side of the field. These are carefully rogued, and the plants which produce the best curds are saved for seed production. When following this method, unselected cauliflower plants should not be allowed to flower in the vicinity. The best means of obtaining good seed is to select a few of the most desirable plants in the field and cage them to prevent cross-pollination. A cage measuring about 4 feet each way and covered with muslin usually gives satisfactory service. If a few flies or other insects are enclosed within the cage, pollination is usually facilitated. It is best to have the sides of the cage held together by screws, as these can be taken out without breaking the boards and the cages stored in the knockdown form. The conditions within the cage usually favor aphis attack, so the plant should be well dusted, or sprayed, when first enclosed. If 25 or 30 ladybird beetles are then enclosed with each plant there will not be much danger of the aphis giving further trouble. The seed from each caged plant should

be harvested separately, and the selections planted side by side in parallel rows for comparison. Under conditions of commercial production, it is best to retain only one of the progeny lots. A number of the best plants within the selected lot should be again caged, and the remainder of the plants open-pollinated, and the seed used for the commercial crop the following year. By following this system, there should be a gradual improvement in uniformity and quality over a period of years.

A large part of the cauliflower seed, especially the early varieties, used in this country is imported from Denmark. This seed is grown mainly on the Island of Amager. It is sown in the fall in seed beds. Later, the plants are transferred to pots and grown in the greenhouse during the winter, and in the spring, they are set in the field. The seed usually matures in September.

Insects and Diseases

Cauliflower is subject to the same insect enemies as cabbage and which have already been discussed. Some of the diseases of cabbage also affect cauliflower; others, which are more specific to this crop, are discussed below.

Whiptail.—Clayton (1924) reports whiptail, a malnutritional disease, as affecting cauliflower on Long Island. The leaves become narrower than is normal, with ruffled and irregular margins. When badly affected, the plants are much dwarfed and do not produce a curd, while the plants less badly affected produce curds that are ricey and leafy. The plants may show whiptail symptoms when very young and later recover and produce normal leaves and curds. Large plants affected by whiptail, however, do not recover. This disease is due generally to unfavorable soil conditions and was found to be much more prevalent on soils heavily treated with commercial fertilizer (1 ton to the acre) than on soil not fertilized. Heavy applications of S (400 pounds to the acre) also produced whiptail. The ill effects of heavy fertilizer and of S applications can be overcome by liming. Clayton states that it is becoming "increasingly difficult to grow potatoes and cauliflower in the same rotation. Liming to prevent whiptail makes conditions favorable for scab; sulphuring to prevent scab predisposes cauliflower to whiptail. Certain growers have already met this situation by setting aside land for two separate rotations." Severe aphis attack may also cause whiptail to develop. Tests conducted on Long Island showed a considerable difference among strains in susceptibility to this disease.

Brown Rot (*Alternaria brassicae*).—Brown rot is mainly a transit disease and develops most rapidly when the temperature and humidity are high. The head is browned and spotted and is unmarketable when infections are numerous. During most seasons, the disease is not sufficiently injurious to justify control measures other than seed-bed and field

rotation. At time of packing, all of the heads which show any brown or decayed spots should be discarded. Weimer (1924) recommends that during shipment the temperature of the refrigerator cars should be held at 6°C. or below.

Ringspot (*Mycosphaerella brassicola*).—Ringspot is prevalent in the San Francisco Bay region of California and near Roseburg and Portland in Oregon but is not widespread elsewhere in America. Nearly all parts of the host plant are susceptible to infection. The blades of the lower leaves are usually most severely affected, although the flower stalks, seed pods, seeds, midribs of the larger leaves, and even the sepals are sometimes attacked. The number of lesions per leaf varies. In extreme cases, almost the entire leaf may be involved and killed. The amount of infection varies with the age of the leaves, becoming less toward the center of the plant. According to Weimer (1926), infection first becomes evident as very small, dark-colored spots surrounded by a band of affected tissues having a water-soaked appearance. The spots are very small at first but may enlarge to a diameter of 1 to 2 centimeters. The lesions are usually circular. The mature lesions are thickly studded with pycnidia or perithecia or both, and they may be scattered or arranged in concentric rings. The fruiting bodies are present on both surfaces of the lesions, although they are usually more abundant on the upper side. Both the pycnidial and the perithecial stages are present during the entire year. The ascospores may be distributed by the wind or carried by workmen walking through the fields. Ringspot may be carried from the seed bed to the field on the plants. Portions of infected pods carried with the seed may be a source of seed-bed infection. It is believed that the fungus normally enters the host through the stomatal pore. After 2 to 4 weeks, the mycelium forms globose masses of cells in the substomatal cavities on both the upper and lower sides of the leaf, which develop into perithecia and pycnidia. The leaf may be so badly injured that it eventually drops from the plant.

As to control, Weimer recommends (1) planting seed in non-infected soil and protection of the seed bed from possible sources of infection by windbreaks and the removal of infected plants from the vicinity; (2) immersing the seeds in water for 10 minutes at 55°C. or for 30 minutes at 50°C.; (3) a system of crop rotation, whereby cruciferous crops are grown on the same land only once in 3 or 4 years, other sources of infection being first eliminated; and (4) for the Colma section, especially "careful selection for hardiness, together with selections of plants with the smallest spots for seed, coupled with the best horticultural practices."

SECTION C. KALE

History.—According to Sturtevant, kale has been under cultivation from a very remote period. Many varieties were cultivated by the

Romans, and it was probably known to the ancient Greeks. Introduction into this country probably took place at an early period.

Plant Characteristics.—The kale group is distinguished mainly by its open habit of growth. It resembles more closely the ancestral type than the other members of this species do. The kale group is exceedingly variable; plants vary in height from tall to dwarf, and the leaves may be variously curled and dissected. The garden kales are grown for their foliage, which is used as greens. The plant is biennial. Flowers, fruit, and seed are similar to those of cabbage.

Production.—Kale is chiefly a fall, winter, and early-spring crop. While very hardy, it does not thrive during extremely hot weather. It will grow on almost any good garden soil, but it prefers a well-drained, fertile, non-acid, sandy loam. In the United States, it is grown most extensively in the South and along the eastern seaboard. The most important area of commercial production is the Norfolk region of Virginia. In this region, the seed of the Scotch varieties is sown in the open field in August or September. Rows are usually planted 30 inches apart, on ridges. When established, the plants are thinned to 12 inches apart in the row. The plants that are pulled in thinning are often used for replanting. The crop is ready to cut for market by November, and harvesting continues throughout the winter. The plants remain edible for a considerable period, but if they become too old before cutting, they are woody. The entire plant aboveground is harvested, then trimmed, packed in barrels, and marketed. The crop is shipped mainly by boat to the northern markets. The Siberian varieties are sown almost a month later and are ready to harvest in February, March, and April. They have plainer leaves than the Scotch and are of a bluish-green color. McWhorter (1924) reports that black rot of kale is somewhat widespread in the Tidewater section of Virginia and causes losses either by reducing the number of plants or by reducing the number of leaves per plant. Methods of control are the same as those practiced for cabbage. Yellows has also been doing considerable damage to the Jersey kale crop, which is grown for chicken feed in the Santa Rosa and Petaluma districts of California. The same insects attack kale as are found on cabbage and cauliflower.

SECTION D. BRUSSELS SPROUTS

History.—Brussels sprouts are supposed to have been grown in the environs of Brussels, Belgium, from a very early period. There is little mention of their cultivation in Europe before about 1800, although they were probably cultivated there long before that time. Thorburn listed one variety in America in 1828.

Plant Characteristics.—The plant is grown for the small, lateral buds in the axils of the leaves. It is a biennial. The stem is unbranched and

erect, the leaves are about as broad as they are long. Flowers, fruit, and seed are similar to those of cabbage.

Production.—Brussels sprouts is mainly a fall, winter, and early-spring crop. Climatic and soil requirements are about the same as for cauliflower. The main area of production is in Suffolk county, New York, located on the eastern part of Long Island. Another area of considerable importance is in the Half Moon Bay region of California. On Long Island, plants for the early crop are set in the field in late June or early July and for the late crop, from July 20 to Aug. 15. The plants are set in checks usually 3 by 2½ feet. Harvesting begins about 3 months after setting. The basal sprouts are the first to mature. They are picked when their outer leaves are just beginning to turn yellow. The leaf subtending the sprout is broken away at time of harvest. Usually, several pickings are made. As the lower leaves and sprouts are removed, the stem continues to elongate and form new leaves and sprouts. The sprouts are graded and then marketed in berry boxes. On Long Island, when freezing weather sets in, the plants are cut off near the ground and then stood upright close together in some protected place and covered lightly with marsh hay, seaweed, or other material. The sprouts may be picked at any time during the winter. They are cut off, and the yellow leaves removed.

Most of the seed used in the large producing centers is grown locally. Plants are selected which have hard, medium-sized sprouts, compactly arranged about the stem and dark green. On Long Island, the mother plants are stored in shallow trenches during the winter and set in the field in the spring. In California, the mother plants are removed from the field and set about 4 by 4 feet in protected beds. The buds are thinned seven or eight to the plant. Often the tips of the buds are clipped off to make it easier for the flower stalks to emerge.

Aphis is the most serious insect pest of this crop.

SECTION E. KOHL-RABI

History.—The early development and history of kohl-rabi seems to be shrouded in mystery. Sturtevant thinks that this vegetable was derived from marrow cabbage and that there is no certain indication of that race in ancient writings. This form of *B. oleracea* is probably of relatively recent origin.

Plant Characteristics.—The plant is a low-growing biennial. The leaves are thin, small, and petiolate and the blades are lyrate and oval to oval-oblong in shape, with irregularly dentate margins and mostly with one or two lobes at the base. The plant is glaucous and glabrous throughout; the stem is short and fleshy and a flattened globe in shape. The enlarged edible portion is above the cotyledons, entirely above-

ground. The reproductive organs are similar to those of other members of the species.

Culture and Handling.—Kohl-rabi is a cool-season crop. Seed is usually planted ½ to 1 inch deep in rows 18 to 24 inches apart and at the rate of 4 to 5 pounds per acre. After thinning, the distance between plants should be about 8 inches. White Vienna is the most popular variety grown in this country. Kohl-rabi is harvested when the fleshy stem is 2½ to 3 inches in diameter; harvesting must be done before the stem becomes woody. As a rule, the crop is sold bunched rather than in bulk. The large tap-root is removed close to the fleshy stem, and about six stems are put in a bunch. Kohl-rabi is not of much importance commercially. The chief demand for it is among the foreign population.

SECTION F. TURNIP

History.—The turnip is thought by some to have been derived from a species growing wild at the present time in Russia, Siberia, and on the

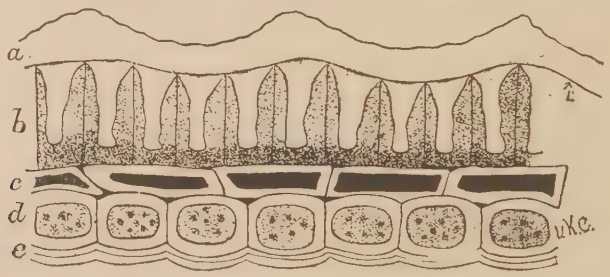

FIG. 32.—Section through outer part of turnip seed; a, epidermis; b, supporting layer; c, pigment layer; d, proteid layer; e, endosperm. (*Pieters and Charles*, 1901.)

Scandinavian peninsula. It was well known to the ancients and was cultivated by them. This crop was introduced into England about 1550, brought to America at a very early period, and is mentioned by Sturtevant as being grown in Canada in 1540, in Virginia in 1609, and in Massachusetts in 1629.

Plant Characteristics.—The turnip is a biennial. Its fleshy, edible portion grows mainly below ground and develops from the primary root and hypocotyl. It is either white or yellow fleshed. The upper part is violet red, green, yellow, or white. The violet-red color is either continuous or spotted. According to Kajanus (1912), the violet color is due to anthocyanin in the outer cell layers of the bark. The green color is due to the chloroplasts in the outer parenchyma layers, and the yellow color is due to the pigment in the walls of the peripheral cork cells. The lower part of the turnip is either white or yellow, depending upon the flesh color. The shape of the root may be conical, spherical, or flat.

The secondary roots arise only from the slender tap-root. The leaves, which arise the first year in the form of a rosette, are grass-green and

hairy, oblong to oval, sometimes entire, serrate, or, in the case of the later ones, pinnate or pinnatifid. During the second season, a stem develops from the terminal bud, bearing leaves which are glaucous, clasping, alternate, lanceolate or oblong, and entire or dentate. The inflorescence is a raceme. Flower color is correlated with flesh color; the yellow-fleshed varieties have pale, orange-yellow flowers, while those with white-fleshed roots have bright-yellow flowers. The flowers are ⅜ inch, or less, long and of a characteristic mustard type, in which the long stamens turn away from the stigma soon after dehiscence. The fruit is about 1½ to 2½ inches long and tipped by a slender beak. The seed is smaller than that of cabbage and reddish brown in color. Seeds of turnip and mustard are very similar; Pieters and Charles (1901) state that their seed coats cannot be distinguished one from the other.

Production.—The turnip crop is grown primarily during the fall in the North and during the fall and winter in the South. It produces best on a rich, sandy loam and is tolerant of acid soil. Seed is usually sown about ½ inch deep in rows 15 to 24 inches apart at the rate of about 2 pounds to the acre. Broadcasting of seed is not practiced as much as formerly. Before they start to crowd, the plants are usually thinned 4 to 6 inches apart in the row. When turnips are to be bunched, they are harvested when about 3 inches in diameter. Most of the crop is marketed in bulk. If stored, it should be kept at a low temperature and in a fairly humid atmosphere.

Breeding.—Kajanus (1911) states that the turnip sets less seed when selfed than rutabagas do under the same conditions. Cross-pollination seems to be far more necessary for turnips than for rutabagas. Furthermore, selfing is more disastrous in the case of the white-fleshed turnip than in the case of the yellow-fleshed turnip. Kajanus (1912) states that three different genes determine the color of the root. One has to do with the flesh color; the other two determine the outer-bark color. *M* is a factor for white and when present acts as an inhibitor for yellow flesh color. *V* is the factor for green, and *P* is the factor for red of the upper bark. When *P* and *V* are absent, the upper bark is cream yellow. *P* apparently dominates *V*. Both are independent of each other and of *M*. The root colors obtained with the different grouping of factors is shown below.

Grouping	Color of upper Bark	Flesh Color
PVM	Red	White
PVm	Red	Yellow
PvM	Red	White
pVM	Green	White
Pvm	Red	Yellow
pVm	Green	Yellow
pvM	Yellow	White
pvm	Yellow	Yellow

The roots are more or less intense in color, depending upon whether they are homozygous or heterozygous with reference to the factors *P* or *V*. *M* is also a gene for flower color, producing a bright yellow.

The turnip and rutabaga can be crossed very readily, especially when the rutabaga is used as the female parent.

SECTION G. RUTABAGA

The rutabaga is a biennial very similar to the turnip. The fleshy portion may be nearly globe shaped, somewhat elongated, or gradually tapering at the base. The upper or aboveground part of the fleshy portion may be violet red, green or various shades between these two; the basal part is either pale, orange yellow or whitish. The stem, or neck, from which the rosette of leaves arises protrudes somewhat. The leaves are bluish white from the deposit of bloom. The yellow-fleshed rutabagas have pale, orange-yellow flowers, and the white-fleshed have bright-yellow flowers.

The method of growing is very similar to that for turnip, except that the crop is somewhat slower growing; the roots grow to a larger size and therefore must be spaced farther apart than turnip.

SECTION H. CHINESE CABBAGE

Chinese cabbage is grown both as a salad crop and a potherb but is not of much economic importance in the United States.

History.—According to Sturtevant, Chinese cabbage has been under cultivation in China at least from the fifth century. It has been grown for a number of years in the United States, but its use has not become general. The Oriental Seed Company, of San Francisco listed eight varieties in their 1927 catalog.

Plant Characteristics and Classification.—Chinese cabbage is an annual. There are two more or less distinct species, the Pe-tsai (*B. pekinensis*) and the Pak-choi (*B. chinensis*). The Pe-tsai resembles cos lettuce, forming an elongated, compact head; the leaves are slightly wrinkled and undulate at the borders, green, thin, and much veined. The midrib is broad and light colored. Basal leaves are 1 to 2 feet long and less than half as broad. Leaves of the flowering branches are mostly clasping. The flowers are light yellow and mostly less than $\frac{3}{8}$ inch long, commonly crowded at the end of the raceme and overtopping the unopened buds. The fruit is $1\frac{1}{4}$ to $2\frac{1}{2}$ inches long, spreading or ascending. The beak is $\frac{1}{6}$ to $\frac{1}{3}$ of the total length of the pod and rather stout. The Pak-choi varieties resemble chard in their habit of growth. The leaves are long, shining dark green, and oblong or oval. This type does not form a compact head. The flowers are pale yellow, and the pods are $1\frac{1}{4}$ to $2\frac{1}{2}$ inches long with a slender beak. The Pe-tsai varieties are the ones used chiefly for market purposes.

Production.—Chinese cabbage is a cool-season crop and is grown mainly during the fall in the North and during late fall and winter in the South. It will grow in a variety of soil types, but it must be fertile and retentive of moisture to give good growth. The seeds are usually sown where the crop is to mature, in rows 24 to 30 inches apart. At time of thinning, the plants are spaced 12 to 15 inches, depending upon the variety. The heads are harvested when firm. The loose, outer leaves are removed, and the heads marketed in various kinds of containers.

Breeding.—There is need for much breeding work to develop uniform strains. The success of the work will depend largely upon the isolation of self-fertile lines. Kakizaki (1922) found that when flowers were selfed, about 30 per cent were entirely sterile. When pollen from other plants was used, a 96 per cent set was obtained. When selfed, a range was obtained from complete fertility to complete sterility, which at least suggests the possibility of being able to isolate strains which are highly self-fertile. Flowers that were bagged but not pollinated artificially gave only about 5 per cent normal pods, a fact which shows that the flowers are so constructed that automatic self-pollination is almost impossible.

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CHAPTER VIII

RAPHANUS

The radish is of widespread cultivation. It is grown mainly as a market-garden crop and is a popular vegetable in home gardens. It is grown as a truck crop to a limited extent only.

History.—According to Sturtevant, China is probably the native home of the radish, though wild radishes exist in the Mediterranean region. Radishes were extensively cultivated by the ancient Egyptians and Greeks. They are reported to have reached England about 1548. They are mentioned as being cultivated in Massachusetts in 1629. In 1828, Thorburn offered nine varieties in his catalog and 25 in 1881. Goff (1887) described 42 varieties which he considered distinct.

Plant Characteristics

The radish is an annual or biennial. It first produces a fleshy tap-root and a rosette of leaves on a much shortened stem, or crown. The plant will usually flower and set seed the first year, but if planted in the fall, flowering is usually delayed until the following spring.

Root.—The tap-root is fleshy; it becomes threadlike and extends deeply into the soil. A few fibrous laterals arise from it; the portion free from laterals is stem tissue developed from the hypocotyl. The ratio of hypocotyl to top root varies considerably among varieties. The roots of the different varieties vary much in size, shape, color, and the length of time they remain in a good edible condition. Uphof (1924) states that the pigment of red radishes is in the epidermis and outer two- or three-cell layers of the cortex. Conrad (1926) found a higher percentage of protopectin, pectin, and pectic acid in radishes than in the roots of other vegetables. The first two made up 26.87 per cent of the dry weight, while the latter made up 15.37 per cent.

Stem.—The upper portion of the edible part of the radish plant develops from the hypocotyl and is therefore stem tissue. The crown of the radish arises from the plumule. After the vegetative period, the stem elongates and becomes much branched, reaching a height of 2 to 3 feet or more. It is usually somewhat glaucous, sparsely pubescent with stiff hairs, especially the lower part, and rarely glabrous throughout.

Leaves.—The leaves are petiolate and glabrous or with sharp hairs; lower leaves are deeply pinnatifid; upper leaves are small and oblong. The rosette leaves vary much in size, according to the variety.

Inflorescence and Flowers.—The inflorescence is a terminal elongated raceme. The flowers are of the typical cruciferous type; rose lilac or white. They are almost entirely insect-pollinated; hence, cross-pollination frequently takes place.

Fruit.—The pods are 1 to 3 inches long and have an extended beak. Pods are several seeded; they are not longitudinally grooved and do not dehisce when ripe.

Seeds.—The seeds are yellowish. Endosperm is almost entirely absent. Waggoner (1917) studied the influence of different temperatures

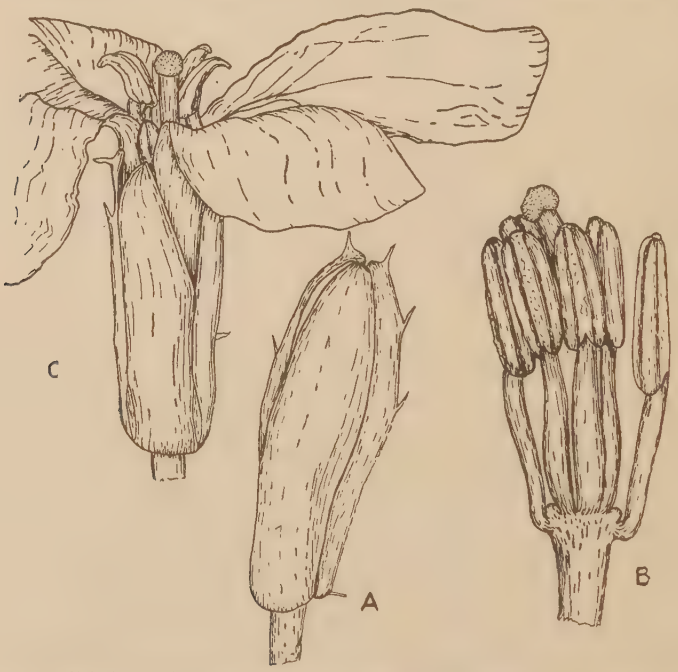

FIG. 33.—A. Radish flower bud just before anthesis. B. The same with sepals and petals removed. C. Radish flower at time of anthesis.

upon the viability of radish seed when the latter contained varying amounts of water. Those with an initial water content of from 0.4 to 71 per cent were heated for 30 minutes at temperatures of 50 to 125°C. After being heated, the percentage germination was obtained. The Icicle variety was used. Waggoner found a definite relation between the initial water content of seeds heated at high temperatures and their viability. Seeds with an initial water content of 71, 50, and 45 per cent are killed when heated at 60°C. for 30 minutes. As the water content decreases, the percentage of viable seeds increases and the critical temperature is raised. For example, as the water content is decreased from 45 to 30 per cent, the lethal temperature shifts from 60 to 65°C.

Air-dry seeds with 4 per cent water give a normal germination when heated at 75°C. but are killed between 95 and 100°C. If only 0.4 per cent water is present at time of heating, viability is unimpaired after 30 minutes at 100°C., but the seeds are killed between 123 to 125°C. The resistance of radish seeds to high temperatures decreases as their initial water content increases. Furthermore, at temperatures high enough to be injurious, the viability of radish seeds of a definite initial water content decreases as the temperature to which they are exposed is raised.

Data regarding the influence of size of seed are rather conflicting. Cummings (1914) states that, regardless of its source, large seed of mixed or unmixed heritage is superior to small seed of the same source, because the former gives larger plants, greater uniformity at edible maturity, and a gain of from 7 to 10 days in maturing. Rotunno (1924), working with a number of varieties, found that in most cases the medium-sized seed gave the heaviest roots as well as the highest percentage of salable roots. Probably the most important thing is to have all the seed of uniform size, so that it will be evenly distributed by the seed drill. Under ordinary conditions, radish seeds remain viable for 6 or 7 years.

FIG. 34.—Dehisced anther of radish.

CLIMATIC AND SOIL REQUIREMENTS

For the early crop, the best type of soil to use is a light, sandy loam, in order to get quick maturity. Later crops should be grown on silty or silty-loam soils, as such soils are cooler and retentive of moisture. Most of the radishes grown are of the quickly maturing type, and therefore readily available inorganic manures are beneficial. Radish grows well on fairly acid soils.

Hendricks and Harvey (1924) were able to make the radish flower and bear seed when grown in artificial light. It bloomed in a light-intensity of 1,400 foot-candles at a temperature of 14°C. It will form a large taproot but will not flower when exposed to short daylight. Garner and Allard (1920) sowed seed of the Scarlet Globe variety May 15 and grew plants with a 7-hour day. The roots continued to enlarge throughout the summer but seed stalks were not formed. Most of the controls which were subject to normal daylight formed flower stems in June. By increasing the length of day to 12 hours, they were able to make the plants form seeds during the winter months, while the plants subject to ordinary daylight continued to vegetate.

Culture

The radish will tolerate considerable frost and may therefore be sown in the spring before danger of frost is over. Where the summers are moderately cool, radishes can be had throughout the entire summer by making successive plantings. The early varieties, however, soon become pithy when the weather is hot. The seed is sown about ½ inch deep in rows 12 to 18 inches apart at the rate of 10 to 12 pounds to the acre. Seed germination is very rapid at ordinary temperatures.

Kotowski (1926) planted radish seed of the Icicle variety 2 centimeters deep in quartz sand at the temperatures shown in Table 26. Germination occurs at 4°C., but only 42 per cent of the seedlings appeared

Table 26.—Germination of Radish Seed at Different Temperatures (*Kotowski*, 1926)

Temperature, °C	4	8	11	18	25	30
First seedling, days after sowing	32	13	10	4	3	3
Last seedling, days after sowing	55	20	15	6	5	5
Seedlings in per cent of seed sown	42	80	92	95	97	95

aboveground after 55 days, and it took 32 days for the first seedling to reach the surface at this temperature. At 25°C., the first seedling appeared 3 days after sowing; in 5 days, 97 per cent of the seedlings had appeared.

When above ground, the cotyledons increase considerably in size and persist for a considerable time. Thinning is seldom practiced, except, occasionally, in the case of winter radishes.

Marketing

Harvesting starts as soon as the roots reach edible size. On the large market gardens, usually only one pulling is made of the early sorts, so it is desirable to have a strain which matures uniformly. The early varieties remain edible for only a short time; the summer varieties, for a somewhat longer period; and the winter varieties, often for several months. Radishes are bunched, washed, and, if they are to be shipped, packed in crates or other containers. The demand for radishes is not great, and there are therefore very few straight carlot shipments; most of the crop is shipped in mixed cars. Winter radishes are usually sold in bulk.

Classification

Radishes may be classified either according to shape of root or season of maturity. The former is useful in helping to identify varieties, while the latter method groups those varieties which are planted and mature at

the same season of the year. Goff (1887) gives three classes, according to root shape: (1) root oblate, spherical, or conical, (2) root more or less distinctly oval, and (3) root conical or cylindri-conical. Relative to time of maturity, they may be grouped into (1) spring, (2) summer and autumn, and (3) winter varieties. In color, the roots may be white, yellow, light brown, grayish, red, purple, or black. The spring varieties (French Breakfast, White Tipped, Scarlet Turnip) are quickly maturing and remain in an edible condition for only a short time. The summer and autumn varieties (White Strasburg) grow to a larger size than the spring varieties and remain in an edible condition longer but do not keep sufficiently well for winter use. The winter varieties (Long White Spanish, Long Black Spanish) grow slowly, reach a very large size, and can be kept for several months under good storage conditions.

Breeding

Frost (1923) finds that much self-sterility exists in radish. Probably in radish, as in many other crucifers, the progress made in improvement will depend to a considerable extent upon the isolation of self-fertile strains. That the cultivated radish and the wild radish (*Raphanus raphanistrum*) cross very readily was demonstrated by Mlle Trouard-Riolle (1920).

A generic cross between radish and cabbage was obtained by Gravatt (1914). The hybrid vigor in this cross was especially marked. The largest leaf was 69 inches long and 19 inches wide. The main stem had a circumference of 13½ inches one foot from the ground. The flowers were both cross- and self-sterile.

Seed Growing

Most of the radish seed grown in the United States is produced in Michigan and California. In California, production is localized in the Santa Clara Valley. The seed is planted in November and December in rows 3 feet apart and at the rate of about 4 pounds per acre. The plants are thinned from 2 to 3 feet apart in the row, depending upon the variety. This thinning is usually done when the roots are of marketable size. For the stock-seed fields, the roots are generally transplanted. The fields are usually in full bloom in April. As soon as the pods turn brown, usually in August or September, the plants are cut and left to dry in small piles about five or six rows apart. Threshing is done with an alfalfa-threshing machine fitted with special screens which will reduce the pods without cracking or skinning the seed. The seeds are then carefully milled to remove cracked and undersized ones.

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CHAPTER IX

ARMORACIA

Horse-radish is widely distributed and is grown for the fleshy-tap roots, which have a very pungent flavor. The roots are ground, preserved in vinegar, and used as a condiment. The pungency is due, according to Friese (1925), to the presence of an allyl iso-thiocyanate (C_2H_5CNS) and a butyl thiocyanate (C_4H_9CNS) similar to the mustard oils occurring in combination with the glucoside sinigrin. The pungent principle is soluble in water but is volatile, hence ground horse-radish needs to be kept in sealed containers.

Commercial production of horse-radish is important near St. Louis, Missouri, where the deep loess soils favor the development of large, smooth roots. Smaller areas are cultivated throughout the North. Horse-radish culture has not been developed in the South, where the long growing season should favor large yields.

Taxonomy.—Horse-radish is placed in various genera by different botanists, thus, *Nasturtium armoricia* Fries, *Roripa armoricia* Hitchc., *Radicula armoricia* Robinson, *Cochlearia amoricia* L., and *Armoracia rusticana* Gaertn. Bailey (1924) gives preference to the last name. Engler thinks that *Cochlearia macrocarpa* var. *hungarica* is the primitive form of horse-radish, but other writers consider this plant the same as ordinary horse-radish escaped from cultivation. Brzezinski (1909) believes that horse-radish is not a natural species but a hybrid. The two distinct classes of plants which he obtained from seedlings indicate that this may be true. He thinks that in Hungary, there may be not one but many wild species of horse-radish, which, by crossing, might have produced the present cultivated form.

History.—Horse-radish is native to eastern Europe, from the Caspian Sea to Finland. Both the leaves and the roots were eaten by the Germans during the Middle Ages, but it was apparently not known to ancient civilized peoples. According to Sturtevant, horse-radish was not introduced into England until 1586 and was probably brought to America during Colonial times, being common here in 1806. Horse-radish tends to escape from cultivation and grow wild, being perpetuated by its perennial roots. Some native American *Cruciferae*, such as the Indian turnip, are characterized by the same pungency as is horse-radish.

Plant Characteristics

Horse-radish is an extremely hardy, perennial plant, although it is usually cultivated as an annual crop. It forms a thick, fleshy, white tap-root, with thickened laterals, which may arise from any portion of the main root but which usually come from the lower end of the original root-cutting, from which the central root is developed. The roots become woody after the first year of growth.

Aboveground, the plant forms a rosette of erect, long-petioled leaves, about 2 feet high. The leaf-blade is tough, long and narrow, dark green, and with crenate or sinuate margins. Occasionally, plants are seen with pinnatifid leaves.

Plants may or may not form a flower stalk, depending upon environmental conditions. The inflorescence is a terminal or axillary raceme of short-pedicelled, small, white flowers. The latter present varying degrees of sterility; at Davis, California, the anthers are usually abortive, and no seeds or pods are formed; in other places, seedless pods have been reported. Brzezinski (1909) observed much variation in size, shape, and degree of pod development as well as of other characters among different individual plants. He observed that in plants with slender pods, the developing ovules become atrophied very early while in the larger pods, some of the ovules continued to enlarge for some time after anthesis. He was able to induce formation of viable seeds by removing, early in June, a band of cortex from the upper portion of the tap-root. While the plants grown from these seeds were very variable, there were two general types, so different that a common origin could hardly be suspected. One type resembled horse-radish in plant and flower characteristics, the other was much dwarfed, with few rosette leaves but numerous flower stalks, which bore flowers throughout the summer.

Climatic and Soil Requirements

The roots are very resistant to freezing, and the leaves are also frost-hardy, though they are generally killed at about −4°C. The plants grow best in a rather cool, humid climate. The cuttings are planted as early as possible in spring, though the enlargement of the roots occurs chiefly in early fall. The soft, friable loess soils and deep sandy loams favor production of large, smooth, unbranched roots for market purposes. On shallow or hard soils, the tendency is to form "sprangly," or branched, roots.

Cultural Methods

Propagation.—The lateral roots, from ¼ to ½ inch thick, are saved at the time when the main roots are trimmed for market. The propagating material is stored over winter in a cool, moist cellar or in a pit out-

doors. The root-cuttings should be 8 to 12 inches long. The roots are cut off squarely, at the end next to the tap-root, and the distal end is cut obliquely, to indicate at planting time which end is to be planted uppermost. The root-cuttings exhibit distinct polarity, in that shoots always arise from the basal part of the cutting (the part adjoining the tap-root). On the other hand, roots may arise from any part of the cutting but mostly from the distal cut end. According to Miss Beals (1923), regeneration of both roots and shoots is from the cambium. Bailey (1901) found that cuttings as short as ¼ inch would produce plants but that well-shaped roots were not produced unless the cuttings were 6 inches long or longer; cuttings planted vertically or slanting made equally good roots, but when laid horizontally, the roots were much branched and worthless; inverted cuttings made shoots from the lower end. Little difference was observed in the crops from cuttings planted with the upper end near the surface or 3 to 7 inches below the surface.

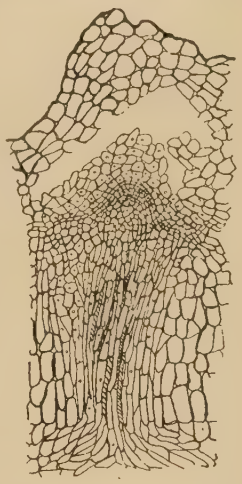

FIG. 35.—Section showing the origin of a vegetative shoot from the cambium of a horse radish root.

Planting.—The cuttings are placed in a slightly slanting position on the side of a deep furrow, a sharp stick being used to open a hole if the cuttings are long. The top of the cutting is covered 2 or 3 inches deep. The planting distance is about 12 by 36 inches. In order to get smooth, thick tap-roots, German farmers make a practice of plowing the soil away from the plants in summer and cutting away the lateral roots and vegetative shoots on the upper portion of the main root.

Harvesting.—The roots are plowed out in late fall, although they may safely be left in the ground over winter. The root system is removed from the soil as completely as possible to avoid a "volunteer" crop of horse-radish the following year, from roots left in the soil. The tops and side roots are removed, and the large roots are washed and packed in barrels for shipment. The roots may be kept in storage in a cool, moist cellar for winter marketing. The yield of marketable roots ranges from 2 to 4 tons per acre. Larger yields can be secured by allowing the plants to grow for two seasons, but the quality is inferior, because of the increased woodiness of the roots.

Varieties.—Most horse-radish is known simply as "common," although the so-called "Bohemian," or "Maliner Kren" variety is used to a limited extent and is supposed to be superior. It is possible that improved strains might be obtained by selecting propagating material from plants with large, symmetrical roots. Brzezinski (1909) is of the opinion that some of the variations observed in horse-radish are

due to propagation of natural seedlings mixed in vegetatively propagated clones.

Insects and Diseases

The only insect which causes severe damage to horse-radish is the harlequin beetle. The control of this insect was discussed in the section on cabbage.

Horse-radish is relatively free also of diseases. A root rot, caused by bacteria, was discovered in New Jersey by Poole (1922). This disease causes a decay of tissues within the vascular cylinder of roots growing in the field and is especially destructive on roots stored in outdoor pits. The root-cuttings at planting time should be clipped at both ends. Those showing any internal discoloration are discarded, while those apparently healthy should be disinfected by soaking for 15 minutes in 0.1 per cent mercuric chloride.

Leaf-spot diseases, caused by various fungi, especially *Ramularia*, *Septoria*, and *Cercospora*, have been reported but are seldom injurious.

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PART VI

LEGUMINOSAE

The legumes constitute one of the largest groups of cultivated plants, including several genera of peas and beans, which may be classed as vegetables. Four of these genera are important as food crops, while many others are of minor importance or are used mostly as forage and green manuring crops.

Phaseolus: This genus includes the common bean (*P. vulgaris*), the scarlet-runner bean (*P. coccineus*), the lima bean (*P. lunatus*), the tepary bean (*P. acutifolius* var. *latifolius*), the mungo bean (*P. aureus*), the adzuki bean (*P. angularis*), the moth bean (*P. aconitifolius*), and several others.

Vicia: The broad, or horse, beans (*V. faba*), as well as the vetches, belong to this genus.

Vigna: The asparagus bean (*V. sesquipedalis*) and the cowpea (*V. sinensis*) are important members of this genus.

Pisum: The garden pea. (*P. Sativum.*)

The genera of legumes are in part, at least, distinguishable by their chromosome numbers. The haploid number is seven in *Pisum* (Cameron, 1903); seven in *Vicia faba,* according to Fraser and Small (1911), though Sharp (1914) considers the number to be six, one of the chromosomes being very long and apparently double; 11 in *Phaseolus vulgaris* (Weinstein, 1926); and 12 in *Dolichos multiflorus* (Nemec, 1910).

CHAPTER X

PHASEOLUS

Beans may be distinguished from peas by the absence of tendrils or of tendril-bearing leaves. Many kinds of beans are climbers, however, by virtue of their sinuous, twining stems.

Many species of beans are native to the Old and the New World. Although botanical relationships are close, divergence from the common origin must have taken place before recorded history began.

According to Vavilov (1926), the species of *Phaseolus* of Asiatic origin are characterized by small flowers, small, cylindrical pods, small seeds, strong pubescence, broad stipules, and long linear bracts. American species of *Phaseolus*, considered in this chapter, have large, flat pods, small stipules, small bracts, a great diversity of large seeds, and are usually glabrous.

SECTION A. COMMON, OR KIDNEY, BEAN

Without doubt, *P. vulgaris* is the most important species from the standpoint of food crops, although its cultivation is comparatively recent, at least so far as white races of man are concerned. This species includes the numerous types and varieties of snap beans and thousands of varieties of field beans, which are grown for use in the dry condition. In our discussion here, we are interested mainly in snap beans, although, in general, these differ from field beans only in that they have a thicker-walled pod, which is relatively free of bast fibers in the earlier stages of development. Some varieties of both groups are used as green-shelled beans.

Taxonomy.—The type of the species is the long-stemmed "pole bean," while the dwarf, or bush, type is classified as *P. vulgaris* var. *humulus*. Alef. In the dwarf type, the main axis terminates in a flower cluster, thus preventing stem elongation; in the pole bean, inflorescences are axillary, hence, the stems may elongate indefinitely. These two types were once considered distinct species, *P. vulgaris* and *P. nanus*. Mendel (1865) was the first to cross these and to study the inheritance of plant habit. Later, Emerson (1904) distinguished a third plant type, the runner bean, intermediate between the dwarf and the pole bean but merging into the latter. Such varieties as Marrow and Navy belong to this group, which is intermediate in length of axis and does not twine sufficiently to enable it to climb a support.

Field-bean varieties are divided into three classes, according to shape and size of seed: (1) Kidney beans are reniform, the length more than twice the width; (2) marrow beans are also reniform but thicker in proportion to length than kidney beans; (3) pea beans are short and more nearly round than the other classes.

Garden-variety, or snap, beans, are subdivided into green-podded and wax, or yellow-podded, groups.

History.—*Phaseolus vulgaris* has never been found in the wild state; it was being cultivated by the Indians in the sixteenth century, from Canada to South America. Thirteen distinct varieties were grown in Chile before the Spanish Conquest, according to Sturtevant (1919). French explorers took from Canada to Europe beans, which became known in England as "French beans." Carrier (1923) quotes the early records of Beverly, as to the culture of "kidney shaped beans" in New England. The Indians interplanted them in corn, a custom which persists to this day among some white farmers.

Plant Characteristics

The plants are annuals, though some species of beans are perennials. The stems are herbaceous, becoming woody in the older parts. In the dwarf varieties, the stems are short and erect; in the runner varieties, 2 to 4 feet long, becoming prostrate; in the pole varieties, stems become 8 to 10 feet long and are distinctly twining. They coil from left to right around supporting objects. Circumnutation begins at the fourth to seventh internode of the main axis. The stems branch very little. In dwarf beans, only four to eight nodes develop on the main axis. In pole beans, the internodes are longer; the number of nodes is limited only by length of growing season.

Leaves.—The leaves are pinnately three-lobed; the leaflets are either broad ovate or long and narrow; the size and the shade of green vary in different varieties. Dark-green stems and leaves usually occur in varieties having deeply pigmented seeds.

Roots.—The tap-root is short with shallow-branching laterals, which go about 15 inches in all directions. The fibrous roots penetrate to considerable depth under suitable soil conditions, hence, beans in many western sections are grown successfully under dry farming conditions. On the roots may occur the nodules formed by the bacterium, *Bacillus radicicola*, which has the power of fixing atmospheric N so that it can be used during the current growing season by the bean plant.

Although the N-fixing bacteria can survive for several years, even in dry soil, they do not occur universally, and it then becomes necessary to inoculate the soil with the proper strain of bacteria. Beans may grow well without inoculation, if N is not deficient in the soil. The usual method of inoculation is to treat the seeds, before planting, in a suspen-

sion of a culture of the bacteria. As far as is known, the strain of *B. radicicola* found on *Phaseolus* is specific for this genus.

Flowers.—The flowers of beans are rather large and showy. *Phaseolus* is distinguished from other beans in that the corolla is much exerted beyond the calyx and the keel is prolonged in a long, spirally twisted beak. The style follows the spirals of the keel. It is bearded below the stigma. The calyx is five-parted. The large and erect single upper petal, the "standard," is bent backward sharply; two laterally extended petals form the "wings," and two lower petals form the "keel." The latter encloses the pistil and stamens. The flowers are white, rose, violet, or yellow. There are ten stamens; the upper one is free, while the other nine are united into a tube enclosing the long ovary. The flowers are in small fascicled inflorescences, on short peduncles. In the pole varieties, the flowering habit is indeterminate. In dwarf varieties, on the other hand, a number of inflorescences develop at about the same time on all the numerous short branches; accordingly, the pods mature at approximately the same time. The flowers usually open between 7 and 8 a.m. and do not close again, the corolla being shed after a few days. The anthers dehisce the evening before the flower opens, making it necessary to emasculate 1 or 2 days before anthesis in cross-pollination work.

Pollination.—Because of the enclosure of the pistil and anthers within the keel, it is difficult for insects to reach these parts, and self-pollination generally takes place. Honey bees, bumble bees, and other insects, however, do visit the flowers and cause some cross-pollination. In most varieties, the amount of crossing is negligible from the seed grower's viewpoint. Emerson (1916) found from 0 to 10 per cent natural cross-pollination in pure lines. In an elaborate experiment with 18 varieties, Kristofferson (1921) reports an average of 1.42 per cent crossing in dry field beans, 0.8 per cent in snap beans, and 0.19 per cent in green-shelled varieties. Many varieties showed no crossing. Self-pollination occurs freely when the flowers are enclosed.

The mature pollen grain is tetrahedral and has a very thick wall with a germ pore at each angle. According to Weinstein (1926), many of the pollen grains begin to germinate 4 to 5 hours before pollination normally occurs, and some develop tubes of considerable length within the anther. Weinstein found that few pollen tubes reach the ovules; most of them do not penetrate the stigma but grow along its surface. A single tube grows through the micropyle and enters the embryo sac within 8 or 9 hours after pollination. The male nuclei are discharged between the egg and the polar nuclei. At first, the endosperm develops more rapidly than the embryo, but in the mature seed the endosperm has entirely disappeared.

Fruit.—The fruit consists of an elongated pod, somewhat compressed laterally and either straight or curved. The pods are two-valved and dehisce, when dry, along the lines of the dorsal and ventral sutures. The

style remains as the tip of the pod. The calyx is not persistent, as it is in peas. The shape of the pod and the number of seeds per pod are varietal characteristics.

Seed.—The seeds are borne alternately on the margins of the two placentae, which are located on the dorsal (upper) side of the pod. The size, shape, and color of the seed vary widely among varieties. The place of attachment to the pod is marked by a scar, the hilum, on one side of which is the micropyle, on the other, a slight ridge, the raphe. Since there is no endosperm, the embryo constitutes the whole seed except the seed coat. The hypocotyl and plumule are well developed, but the great mass of the seed consists of the cotyledons, in which are stored large quantities of carbohydrates and proteins.

Gloyer (1920) has described two types of hardness in beans, sclerma, a hardening of the cotyledons, and hard-shell, a toughening of the seed coat. Sclerma is said to result from enzymatic changes induced by storing seeds in high humidity and high temperature without ventilation. Hard-shell may occur in beans while stored at high temperature and low humidity or in beans ripening during hot, dry weather. It is overcome by storage for a period in a moist atmosphere.

The viability of bean seeds under favorable storage conditions does not deteriorate markedly until after the fourth year; Rapp (1920) obtained the following results in Oklahoma (the data give the average results with four varieties):

Age	Per cent, germination on tester	Per cent, in field planting
1-year old	98.5	92.0
2-year old	92.5	91.0
3-year old	92.5	70.0
4-year old	83.5	58.0
5-year old	35.0	22.0

Rapp found considerable difference in the longevity of various varieties, though in all cases, 3-year-old seed could be planted safely.

Germination.—Seasonal variation in the germination of beans is said by Gloyer (1920) to be due to changes in the permeability of the seed coat.

Soaking beans in water for 6 hours at temperatures ranging from 5 to 20°C. was found by Kidd and West (1918) not to affect the per cent or speed of germination, but the subsequent growth was decidedly inferior to that of untreated seeds, presumably because of the leaching of nutrients from the seed. So marked is the deleterious effect of soaking, that Leonard (1924) found it advisable to use dry soil instead of water as the medium for inoculating beans with the N-fixing bacteria.

Size of Seed and Crop Production.—Cummings (1914) found in the Golden Wax snap bean and other varieties that the weight of green pods produced per plant increased with the size of seed planted and that the difference between large and small seed was sufficient to warrant the elimination of the latter, as shown in the following table:

Size of seed	Weight of 500 seeds, grams	Weight of green pods produced, grams	Average weight of green pods per plant, grams	Average weight of dry beans per plant, grams
Large	312	5,894	13.8	2.26
Medium	252	4,762	11.1	1.45
Small	169	3,629	9.8	1.53

In experiments with Lima and soy beans and other plants, Schmidt (1924) observed that light seed generally germinates more rapidly than heavy seed. In the seedling stage, however, the larger seeds showed an advantage by developing a longer hypocotyl and larger primary leaves. The increase in dry weight and leaf area is sometimes maintained throughout the growth period of the plant, though often plants from small seed overtake those from large seed before maturity. Harris (1914) found that there is a positive correlation between number of pods produced by the plant and the weight of the seed. Abnormally heavy seeds did not, however, give as favorable results as those of high medium weight. Harris (1912) showed that very heavy seeds were subject to a greater mortality, when planted in the field, than medium to large seeds.

Rudolphs (1923) found that temperature, acting as an accelerating factor, increases the advantage of plants grown from the larger seeds. At 20°C., the growth rate of seedlings from large beans was much more rapid than from small ones; at 10°C., seedling growth rate was the same, regardless of size of seed.

Climatic and Soil Relationships

All varieties of *P. vulgaris* are sensitive to frost. Snap beans, being used immature, require a very short season and can be grown almost to the Arctic Circle. In New York state, snap beans require from 47 to 66 days to reach harvest stage. Dry beans are produced most abundantly in the North—in the states too far north for the successful production of corn. Kotowski (1926) finds that the minimum temperature for germination is between 11 and 18°C. At 11°C., only the radicles elongated, while at 8°C., the seed remains dormant but germinates promptly when removed to favorable temperature. The optimum temperature for germination is about 25°C.

Snap beans are grown extensively in all parts of the country, though commercial production is largely in the South, where the crop is grown

chiefly in spring. Often a second, or fall, crop is grown. The ravages of the bean weevil are the chief limitation on production of dry beans in the South. All types of beans are grown extensively in the western states, under both irrigation and dry-farming conditions. The dryness of the growing season limits the diseases and favors the maturation and harvesting of beans.

Beans thrive best on deep, well-drained soils. Good drainage is important, because of its relation to soil temperature. Soils high in Ca are considered best for beans; the plants respond to application of lime on acid soils. Beans are grown successfully on more or less alkaline soils in California; Hendry (1918) finds cowpeas, horsebeans, and Garbanzo beans most resistant to high concentrations of sodium chloride; Lima and Tepary beans are moderately resistant, and varieties of *P. vulgaris*, most susceptible.

Cultural Considerations

Plantings usually begin about the time of the average frost-free date for a given locality. Those made after the soil temperature has risen often give the best results. In California, beans are frequently grown following winter grain. Two methods of planting are practiced—the hill and the drill. The latter is most common with dwarf and runner types, the rows being 28 to 34 inches apart. Special bean planters, or corn planters with plates adapted to beans, are used for field planting. The rate of seeding varies with the size of the seed.

An experiment to determine the proper spacing in the row is reported by Gillis (1923) as follows, the yield being in pounds of green snap beans per acre:

Variety	Number of plants per linear foot		
	Two per foot	Three per foot	Six per foot
Red Valentine	7,396	8,728	9,567
Stringless Greenpod	7,305	8,717	9,352
Refugee Wax	8,831	9,687	10,197

On account of the increased cost of the seed, the higher yields produced by closer planting may not always be profitable.

Pole varieties are usually planted in hills 30 to 36 inches apart, for convenience in supporting the plants. Several plants are allowed to grow in each hill. Stakes about 1 inch in diameter and 7 to 8 feet long are placed beside each hill before the stems start to climb. Although staking is expensive, it is necessary for the pole varieties of snap beans. These varieties are very heavy yielders and bear their crop over a longer period than do dwarf beans. Furthermore, varieties of the pole type are in

special demand on some markets. Pole varieties for seed are grown without supports in California.

Harvesting

Harvesting of snap beans is done entirely by hand; three to four pickings at intervals of a few days will harvest most of the crop from bush varieties, but picking is continuous over a long season with pole varieties. At the best edible stage, the pods have reached their full size, but the seeds are only about one-fourth developed. When the seeds are so large that constrictions in the pod are evident, the best edible stage is passed. During the latter stages of development, the parenchyma cells of the pod become lignified and are more or less compressed; bast fibers become more numerous, especially along the sutures, so that even the so-called stringless varieties become fibrous. Extensive snap-bean culture is limited to sections where an adequate supply of cheap labor is available. After picking, broken or diseased pods, leaves, and bits of stems are sorted out, and the beans are packed in hampers, or baskets. The beans should be dry; otherwise, they will heat and mold during shipment.

Harvesting of dry beans is better adapted to large-scale operations. The plants are allowed to grow until the majority of the pods are brown and dry. If allowed to grow until all the pods are mature, some of the earlier ones split open, and the seeds are lost. The tendency to shatter is partly a variety characteristic, but climatic conditions are also important.

Two-row bean harvesters are used to pull the plants. These machines have blades to cut the stems below the surface of the ground; the two rows are drawn together in a windrow and left to dry for a day or two and are then thrown into small cocks to complete drying and await threshing. Ordinary grain threshers are sometimes used for beans; these are run at a reduced speed and further modified by the removal of all but one row of the concave teeth and half of the cylinder teeth. Special bean-threshing machines are more satisfactory, however, resulting in fewer split seeds. After threshing, the seeds are cleaned in a fanning mill and are passed over a grading table for removal of imperfect, discolored, or split beans.

Marketing

Snap beans are produced for local markets throughout the central and northern parts of the country during summer and early fall. Extensive acreages are grown in the South Atlantic and Gulf states, as a spring crop for shipment to northern markets. Because of their perishable nature, snap beans for shipment must be placed under refrigeration very soon after picking. Bunker icing only is practiced in shipping beans in refrigerator cars, as the beans must be kept dry to prevent soft rot and mold upon removal from the car.

Snap beans are canned extensively in western New York, Maryland, and California.

Dry beans are a stable commodity, being sold on grade and according to variety. They may be kept in dry storage for more than a year.

Varieties

Desirable varieties of snap beans should be early in maturing, high yielding, disease resistant, adapted to climatic conditions, attractive in appearance, and of suitable color, form, and other physical characteristics to meet the demands of the market for which they are intended. Improvement of bean varieties has been rapid in recent years, the work of N. B. Keeney and Sons, of LeRoy, New York, being outstanding.

For canning purposes, the most popular type of green-podded snap bean is the Stringless Green Refugee. In Maryland and Delaware, the older Giant Stringless type is being used for packing of cut beans. In California, Kentucky Wonder and Blue Lake are used for canning. Of wax-podded beans, the leading varieties for canning are Burpee's New Kidney Wax and Improved Kidney Wax, which are almost stringless and have the right sizes for packing whole beans. In general, canners prefer round-podded green beans and semi-round-podded wax beans.

Although, on the markets, wax beans are often more popular than green-podded varieties, growers usually prefer the latter because of their supposedly greater resistance to disease and vigor of growth. Some important market varieties are as follows:

Bountiful (Dwarf).—Pods light green, long, straight or slightly curved, flat in cross-section, brittle, stringless, and remaining edible till fully grown. The dry seeds are medium to large and dull yellow in color.

Round-pod Kidney Wax (**Brittle Wax,** Dwarf).—Pods yellow, medium to large, curved, round in cross-section, deeply crease-backed, brittle, stringless. The dry seeds are medium sized, long, kidney shaped, and white with irregular black markings about the eye (hilum).

Burpee's Stringless Greenpod (Dwarf).—Pods dark green, medium length, curved, round in cross-section, crease-backed, showing outline of seeds before fully grown, brittle, and stringless. The dry seeds are coffee brown with nearly black shading about the hilum.

Refugee Wax (Dwarf).—Pods light yellow, small, curved, round in cross-section. The improved strains are stringless. Flowers pink.

Golden Wax (Dwarf).—Pods light yellow, straight, flat podded, and slightly fibrous. Flowers white.

Refugee 1,000 to 1 (Dwarf).—Pods green, long, slender, curved, round in cross-section, becoming fibrous if allowed to grow to full maturity. Keeney's Stringless Refugee is said to be a new stringless strain.

Kentucky Wonder (Pole).—Pods green, 8 to 12 inches long, irregularly curved, showing constrictions between the seed. The seeds are greenish brown. There are also white-seeded and wax-podded strains.

In 1921, American seedsmen listed 962 varieties of dwarf snap beans and 604 pole varieties, beside many varieties of miscellaneous types. That many of these varietal names are synonymous is indicated by the fact that 63 per cent were listed by only one seedsman. The number of distinct varieties in beans, is, however, unusually large, especially in the field-bean classes. Probably the prevalence of self-fertilization in beans has aided in the preservation of many distinct types arising as mutations or resulting from occasional cross-pollinations. Varietal monographs of American varieties have been made by Irish (1901), who based his primary classification on shape and color of seed, and by Jarvis (1908). Jarvis gives an excellent varietal key, based mostly on seed characters and complete varietal descriptions.

Breeding

Emerson (1904) studied the inheritance of plant habit. He concluded that involved in determining plant habit are three distinct genetic factors, which govern length of plant axis, twining habit, and axial vs. terminal location of inflorescences. Pole may arise from crosses between bush and runner varieties; and runner beans, from crosses of bush × pole. In crosses of bush × runner or pole varieties, the axial pod character of the latter was always dominant in F_1, with approximately 3 : 1 segregation in F_2. Some of Mendel's results indicate that long is dominant over short plant axis with 3 : 1 segregation, though Norton (1915) found the length of plant axis to be governed apparently by a series of two or more genetic factors for length. The twining habit (circumnutation) is dominant over straight stems, according to Norton. Thus, with several characters and genetic factors concerned, it is not surprising that a variety of plant types may arise from bush × runner or pole crosses.

With reference to pod quality, snap beans are either stringy or stringless and tough or tender. Stringy varieties have, along both sutures, strongly developed bast fibers, which are nearly absent in stringless varieties. Tough-podded varieties have numerous fine, strong fibers running obliquely from suture to suture; pods of tender varieties lack these fibers, are fleshy, and shrivel up at maturity without dehiscing, whereas the tough-podded type dehisc, often expelling the seed forcibly. In crosses of stringy × stringless varieties, Emerson found the F_1 pods to be sometimes intermediate; in other cases, stringless was almost completely dominant. In F_2, the recessive character—strong suture fibers—appeared in about one third of the plants, and F_2 plants selected for this character bred true in F_3. Of those selected for stringless pods, some bred true in F_3, others (heterozygotes) produced both types again. Because

of the mode of inheritance of this character, it would be almost impossible to isolate a stringless variety by mass selection; testing of single plant progenies in F_3 is necessary.

Pods of the so-called wax bean vary from yellowish to almost pure white; this class is differentiated from the green-podded type by the disappearance of chlorophyll in the early stages of development, though the green pods also loose their chlorophyll toward maturity. In crosses between the two types, Emerson found the green color to be dominant, with 3:1 segregation in F_2. Other pod colors are blue green and purple, due to the presence of varying amounts of anthocyanin. In both wax and green-pod varieties, the presence of this pigment is dominant over its absence.

The flower color agrees to some extent with seed color; white flowers occur in all white-seeded or -eyed varieties. The darker the seed coat, the deeper the pink-purple pigmentation of the flower. In crosses, the dark color is usually dominant. Colored flowers often appear in crosses between slightly colored varieties. The genetics of flower and of seed color in beans appears to be very complicated, and no generalization can be made from known relations in other hybrids involving the same color combinations. Crosses between solid-colored varieties usually produce solid-colored progenies but in some cases give rise to mottled forms, some of which breed true. Emerson (1909) explains this on the theory that there are two genetic factors for mottling, which exist separately in heterozygous individuals but are linked in those which breed true for mottling. Shaw and Norton (1918), as a result of crosses between many varieties of snap beans, found that, in general, pigmented $\times$ white gave 3:1 ratios in F_2, pigmented being dominant; but there are many exceptions. They believed that they found also a factor existing for total pigmentation of seed and that if this is absent when the factor for pigmentation is present, an eyed bean results. Pigment colors and pigment patterns are governed by different factors. Sax (1926) finds also that the factors for pigmentation, mottling, and extension of pigment, are inherited independently. Thus, in a cross of Symonds White bean $\times$ a small eyed bean, the F_2 segregates gave a ratio of 27 mottled: 9 self-colored: 12 eyed: 16 white. Some linkage was found between factors for pigment extension and yield; yield was found also to be associated with plant type, the runner segregates being twice as productive as the bush segregates, although this relation was opposite that of the parental varieties. Date of bloom, leaf type, seed weight, and yield per plant appear to be dependent on multiple factors in each case.

Malinowski (1923) finds that seed shape in beans is determined by cumulative genetic factors for length, width, and thickness, which are closely linked. The same worker (1921) discovered that heterosis was exhibited in only two intervarietal crosses out of 50 tested. The F_1

plants of these far exceeded either parent in vegetative development; they grew for a longer period, matured late, and produced few pods. The phenomenon of heterosis in beans is explained by Malinowski by the operation of three complementary genetic factors.

Much breeding work of practical value has been accomplished in beans by the selection of improved types from commercial strains, taking advantage of variations caused chiefly by chance crossing. Mutations are very rare in pure lines; Johansen (1909) observed only two in the numerous lines grown by him over a 10-year period. His classical experiments (1903) demonstrating the stability of pure lines are of special interest. By the initial selection within the variety Princess, he isolated strains varying in seed weight. Further selection within these pure lines for large and small seeds, continuously for seven generations, resulted in no appreciable differences. In the variety Chevier, which has white, green, and green-white seeds on the same plant, Fruwirth (1917) made selections for nine generations without being able to isolate a strain having uniform-colored seeds or to intensify the normal green-seeded type.

Diseases

Bacterial Blight (*Bacterium phaseoli*).—In the central and eastern states, this disease causes extensive losses both to snap and to dry beans. The leaf lesions begin as wilted spots, which enlarge as the tissue yellows and dies. The plants may be completely defoliated, or the stems may be girdled just above the cotyledons, causing the plant to wilt. Spots occur also on the pods, as irregular, brownish patches, affecting only the surface or passing through the pod. The seed may be much shriveled and discolored or may show only a yellow tinge around the hilum. Many seeds so affected either form abnormal seedlings or do not germinate. In plants from affected seed, the bacteria pass from the cotyledons into other parts of the plant through the vessels. The disease is perpetuated from year to year in the seed, also in refuse in the field. High temperature and high humidity favor the rapid development of the disease and its spread from plant to plant. Such measures as spraying and seed treatment have little effect in controlling the disease. Sanitary precautions to prevent overwintering of the bacteria in the bean straw and the use of healthy seeds are the most important preventatives. Disease-free seed may be secured from dry western sections, where the disease does not occur, or by the use of old seed. Rapp (1920) found that the bacteria died out in the seed after a time and that very little blight occurred when seeds 2 or 3 years old were planted. Since beans retain their viability for about 4 years, this is a safe and practical control measure. Another means of getting healthy seeds on a small scale is the hand picking of dry pods, which show no disease lesions and which therefore contain disease-free seed. Rapp observed considerable difference in susceptibility of

varieties to bacterial blight, Stringless Greenpod, Refugee Wax, Kentucky Wonder, and Unrivaled Wax being the most resistant of the snap beans. Gloyer (1924) observed that relatively late plantings in New York were less affected by blight, also that the apparent resistance of some varieties was due to the delay in pod formation until the cool days of September.

Burkholder (1924) found that no variety possessed complete immunity to bacterial blight and that single plant selections from the most resistant varieties failed to yield increased resistance. The most resistant varieties of snap beans in New York were Keeney's Rustless Golden Wax and Stringless Green Refugee, while Robust was the most resistant of the field beans.

Bacterial Wilt (*Bacterium flaccumfaciens*).—This disease is caused by an organism very similar to that causing bacterial blight, and the symptoms are so similar that the two diseases have usually not been differentiated. Miss Hedges (1926) shows, however, that the wilt organism does not cause stomatal infection, as does the blight organism, and that the former is not accompanied by conspicuous yellowing of the leaves; in pod infections, the wilt follows the sutures, while the blight causes spots. The wilt organism in the seed resists desiccation for a much longer time (even 5 years) than the blight bacteria. Rands and Brotherton (1925) find that varieties resistant to blight may be very susceptible to bacterial wilt. Use of disease-free seed is the principal control measure. Bacterial wilt occurs in both eastern and western districts, hence western seeds are not always wilt free.

Anthracnose (*Colletotrichum lindemuthianum*).—In occasional years, this disease is epidemic on both snap and field beans in humid regions, causing very extensive losses. Although other species may be infected, the disease is serious only on varieties belonging to *P. vulgaris*. Edgerton (1916) showed that there were several different strains of the anthracnose fungus and that some varieties were resistant to some strains of the fungus but not to others. There seems to be a very delicate adjustment between host and fungus, with reference to parasitism, in this disease.

On the leaves, anthracnose causes angular brown areas on the upper surface, with blackening of the veins conspicuous on the undersurface, which serves to distinguish it from bacterial blight; in advanced stages, the leaves fall. On the pods, there are sunken brown spots, black in the center. They enlarge slowly in diameter and depth, until the canker passes through the pod wall into the seeds below. The pod infections may render a large part of the crop unmarketable, in the case of snap beans, without severely affecting the plants. Furthermore, the lesions may develop on apparently healthy pods during shipment. On the dry seed, anthracnose causes characteristic blackening of the affected parts, which may be bordered by a brown or tan-colored fringe. Infected seed

may not germinate, or it may produce seedlings which drop the cotyledons or in which stem lesions appear early.

The fungus overwinters in infected seed and in diseased plant parts left in the field. It is sensitive to heat and dryness, is not active in the southern states during summer, and does not occur in dry western sections. As in the case of wilt and blight, neither spraying nor seed treatment are effective control measures. Hand picking the seeds, eliminating all deformed and discolored ones, will reduce seed transmission but will not eliminate it, even in white-seeded varieties, where seed infection is most visible. Seeds from healthy pods are disease free and will produce healthy plants, which, however, may become infected during the growing season if diseased beans are nearby and weather conditions are moist, favoring the spread of the disease. Edgerton found that healthy seed could be produced in Louisiana by growing the crop in late summer and fall, when conditions are unfavorable for the fungus. Seed beans from western dry sections are free of anthracnose.

In snap beans, little progress has been made in production of anthracnose-resistant varieties, but in dry field beans, several highly resistant varieties are in use. Leach (1923) distinguished eight strains of the fungus; he found that the fungus hyphae could enter the tissues of resistant varieties but made little progress, because of the autolytic destruction of the fungus within the host plant. Barrus (1915) found the Wells Red Kidney and Imperial White to be resistant to alpha and beta strains of anthracnose but not to the gamma strain, which, however, is not widely distributed. From these, by crossing and selection, several commercially desirable anthracnose-resistant varieties have been developed. Burkholder (1918) crossed the resistant Red Kidney × White Marrow (susceptible). In the F_2 generation, resistant and susceptible plants were produced in nearly 3:1 ratio, resistance being dominant. From the progeny, resistant strains of White Marrow, Vineless Marrow, and White Kidney types were isolated. McRostie (1919) crossed Wells Red Kidney × Robust, the latter being a white pea-bean susceptible to anthracnose but resistant to Mosaic. His results on inheritance of anthracnose resistance were similar to Burkholder's.

Rust (*Uromyces appendiculatus*).—This disease is common in the central and eastern states and occurs in the coastal portions of the Pacific states. The rust pustules appear on all aerial portions of the plants, especially on the undersides of the leaves and on the pods. They are small, circular, raised sori, containing spores, which are reddish at first, later turning black. Severely affected leaves are killed; the plants may be entirely defoliated. All stages of the fungus occur on the bean plant, which is the only host. Both urediospores and teliospores may overwinter on dead plants or in the soil, causing infection in the spring to young plants. Control is difficult, since spraying and other prophylactic

methods are not effective. The terms "rust proof" and "rustless," as used by seedsmen, usually refer to varietal resistance to anthracnose and not rust disease. Fromme and Wingard (1921) found the following varieties of snap beans to be resistant in Virginia: Hodson Green Pod, Refugee, Wardwell's, Challenge, Flageolet, and Black Valentine (bush beans); and Marblehead, Tennessee Wonder, and Mount d'Or (pole beans). The widely grown Kentucky Wonder and White Creasback are very susceptible but there is a resistant strain of the former. Red Kidney, White Kidney, and White Marrow are resistant dry beans.

Dry Root Rot (*Fusarium martii phaseoli*).—There are probably several organisms causing root rot of beans. Thus, Weimer and Harter (1926) found four distinct species of Fusarium causing root rot in California. This disease occurs in all parts of the country, and all kinds of beans are susceptible. Part or all of the roots and the lower part of the stem may be affected, either in the seedling or adult stage. Affected parts develop a brownish, dry decay. The upper part of the plant may be killed, or it may be stunted and set very few pods. As the lower roots are killed, adventitious roots may form near the surface, if the soil is moist. The fungus survives in the soil indefinitely, though a 5-year rotation reduces the infection. Burkholder (1919) found a late-maturing, flat-seeded type of the White Marrow bean to be fairly resistant. Although the factor for resistance is inherited in crosses with non-resistant varieties, the mode of inheritance is complicated.

Mosaic.—Mosaic is very destructive on dry beans in the northeastern states but is not often a serious disease of snap beans. The leaves of an infected snap bean have the characteristic light-yellow and dark-green mottling, with surface-puckering and distortion. The plants are not killed, but production of pods is reduced. The disease is transmitted in the seed, this being one of the few mosaic diseases in which seed transmission has been proved. Beans from slightly infected plants give rise to more severely affected plants, which will produce no seed but serve as a source of inoculation for adjoining healthy plants. Insects probably are chiefly responsible for spreading the disease in the field. The disease is controlled chiefly by the use of seed from a field where the disease did not occur or by the use of resistant varieties. The Robust, a dry bean of the small Navy type, developed at the Michigan Experiment Station, is almost entirely immune. Snap beans more or less resistant include German Black Wax, Refugee Wax, Scarlet Flageolet, and Red Valentine.

Insects

The Bean Weevil.—Closely related to the pea weevil, this insect is chiefly a storage pest of dry beans. It occurs almost wherever beans are grown. The adults lay eggs on the pods during the growing season; the small white larvae hatch in from 5 to 20 days, depending on the tem-

perature. They bore through the pod into the seeds, where they feed for 11 to 42 days before pupating. Pupation occurs in the seed also, requiring from 5 to 18 days. Bean weevils are more numerous in the south, because higher temperatures speed up the life cycle, so that more generations occur in one year.

The weevils are in the beans in the larval or pupal stage when the beans go into storage. Adults emerge during the storage period and start the life cycle anew. Hence, beans which are apparently sound when placed in storage, may be completely ruined by spring. The larvae channel through the seed without rupturing the seed coats, but after pupation, the adults cut their way out, leaving the seed honeycombed with circular holes. Most of the weevil feeding is in the cotyledons; hence, weevil-infected seeds often germinate when planted, although the growth may not be vigorous. The weevils emerging from such seeds, however, survive also and may reinfest the next crop of beans.

Control consists of measures to limit the number of insects in the field and of killing those weevils taken into storage in the beans. Fumigation with carbon bisulfide at the beginning of the storage season is the most general control method. The fumes are heavier than air and penetrate downward through the mass of beans when the liquid is poured on the upper surface. Any quantity may be fumigated, from a few pounds to several tons. The dosage is 3 to 8 pounds of carbon bisulphide for each 1,000 cubic feet of space to be fumigated; the smaller dosage is used when the container is air-tight and the temperature high. The most efficient temperature for fumigation is 75°F., while at 60°F., or below, it is not effective. Heat also destroys weevils and, if properly regulated, does not injure viability; 120 to 145°F., for 5 to 6 hours is safe and effective, if the beans are spread out in a thin layer.

Mexican Bean Beetle.—Although long known to exist in the arid Southwest, it was not until 1918 that this insect was introduced into the humid parts of the country. It appeared first in Alabama and has since spread rapidly. It attacks all kinds of beans and several other kinds of vegetables. The adult beetle is about $\frac{1}{5}$ inch long, nearly round, and yellow to copper colored, with 16 black spots in three lines across the wing covers on its back. Eggs are laid on the under sides of the leaves. They hatch in 5 to 6 days, and the larvae begin at once to devour the foliage. They skeletonize the leaf, leaving the veins and upper epidermis. Spraying with arsenicals does not seem to be effective as a control measure, but sanitary precautions and the destruction of the overwintering adults in trash and dead plants reduces the number of beetles the following year.

SECTION B. LIMA BEANS

Lima beans are used shelled, both in the green and dry state. Production of green-shelled Limas, on a rather limited scale for local markets,

is carried on throughout the South and East as far north as New York. In New Jersey and western New York, considerable quantities are canned. Dry Lima beans are grown almost exclusively in the fog belt or coastal regions of southern California. Commercial production began in the Carpenteria Valley in 1875, largely through the activities of Henry Fish. The Henderson and other dwarf types are grown in the interior valleys of California. Most of the seed crop is also grown in California.

Taxonomy.—Bailey (1886) divided Lima beans into two main groups, the Sieva, or Carolina, having small seeds, being considered the type of the Linnean species *P. lunatus;* the large-seeded type, or the true Lima, was classified as *P. lunatus* var. *macrocarpus.*

In the former group, the plants are rather small, slender, early maturing, and comparatively hardy to low temperatures. Plants of this group have thin, short, broad, ovate-pointed leaflets, except in the Willow-Leaf Lima, which has long, narrow leaflets. The pods are numerous, small, and papery; they readily split open upon maturity. The seeds are small, flat, and are white, brown, red, or speckled.

True Lima beans are distinguished from the Sieva type by their tall growth, late maturity, and greater susceptibility to cold. They are perennial in tropical countries. The leaflets are large, thick, and ovate-lanceolate. The pods are fewer, more fleshy, and often curved laterally. They are less inclined to shatter upon maturity. The seeds are relatively large and are white, red, black, or speckled. The seeds of white varieties of Limas are more or less green in the immature state, and the greenish color of canned beans, and sometimes of dry beans, is due to harvesting immature.

Bush and climbing varieties occur in each of the groups of Lima beans; they are apparently of recent development.

History.—Lima beans are of American origin, having been cultivated here in prehistoric times. The seeds have been found in mummy pits in Peru, and the plants grow wild in the Amazon basin in Brazil. They were first described, in 1558, as the "American Faba bean," since they resembled *Vicia faba,* the common bean of Europe and of antiquity. According to Sturtevant (1889), McMahon, in 1806, was the first writer to apply the name "Lima." In about 1824, the culture of the large Lima bean became general in the United States, through the introduction of seeds from Lima, Peru, by Capt. John Harris, U. S. N. The Sieva type was grown in the Carolinas as early as 1700, according to Lawson, and may have been grown by the southern Indians even earlier. Varieties of the Sieva type, known as the Hopi, have recently been obtained from the Indian tribe of that name, in Arizona, where they have been cultivated for centuries.

The dwarf, or bush, varieties have apparently arisen in recent times as mutations. Bailey (1895) records the details concerning three of them. The Burpee Bush Lima came from a single dwarf plant, observed by Asa

Palmer at Kennett Square, Pennsylvania, in 1883. Dreer's Bush Lima came from selections of dwarf plants in the Challenger variety of pole Limas, by J. W. Kummerly, of Newark, New Jersey, and was introduced in 1889. This variety tends to revert to an intermediate form of runner beans. The Henderson Bush Lima was found in Virginia in about 1875, though it was not introduced to the seed trade until 1890.

Plant Characteristics

Plant characteristics are very similar to those of *P. vulgaris*. The leaves are glabrous. The flatness of pods and seeds are also distinguishing characteristics. The flowers are nearly always white and are in a long, peduncled raceme. Lima beans have a strongly developed tap-root, which penetrates 3 to 6 feet, with laterals distributed sparingly along the entire length.

Climatic Relationships

The northern limits of Lima bean culture are determined by the plant's sensitiveness to low temperatures and by the relatively long growing season required. Green-shelled Lima beans, however, can be grown in most parts of the United States. Temperatures above 16°C. are required for the germination of Lima beans; when planted in moist soils below this temperature, the seeds decay.

In the production of dry Lima beans, especially of the large-seeded type, temperature and humidity of the air are very important. Conditions near the coast of southern California seem to be nearly ideal, because of the moderately warm, long growing season and the presence of fogs, which prevent excessive shattering of the dry pods. On the central and northern coast of California, the number of heat units received, even in a long frost-free season of 235 days, is not sufficient to ripen the pods (Hendry, 1921). In the warm, dry, interior valleys of California, shattering may be excessive, and blossoms developing during extremely hot weather abscis without setting. The Henderson Bush and Hopi Lima varieties are more resistant to these conditions than large-seeded types and set pods under conditions of great heat and dryness.

Soil texture seems to affect the time of maturity, sandy soils maturing the crop earlier than clay soils. Shaw and Goodwin (1911) ascribe this primarily to the more abundant moisture in heavy soils; factors tending to delay maturity result in a larger yield where the growing season is sufficiently long.

Cultural Considerations

Cultural methods for Lima beans are not very different from those for varieties of *P. vulgaris*. Planting is somewhat later in spring, because of the higher temperature requirement for germination. For green-shelled-

bean production, with pole varieties, planting in hills and supporting by stakes is the rule. Bush varieties are usually drilled. For dry-bean production, all varieties are drilled, and the pole varieties are allowed to spread on the ground without support. Row width varies from 30 inches for bush to 48 inches for pole varieties, and spacing in the row varies from 8 to 18 inches, according to the variety. The small-seeded types are planted with ordinary seed drills, but for the large-seeded varieties, special planters, designed to drop only one seed in a place, are employed.

Most of the dry Lima beans are produced under dry-farming conditions, where the rainfall in some cases is as low as 10 inches per year, but where the evaporation rate is low because of the moderate temperature and high atmospheric humidity in coastal regions. The small-seeded Limas, especially the so-called "baby" Limas of the Henderson Bush type, are grown under irrigation.

Harvesting

Limas for use as green-shelled beans are picked by hand. Two or three pickings at 10-day intervals are sufficient to gather most of the crop in bush varieties, but for pole varieties, the picking season is limited only by the length of the frost-free period. The beans attain their greatest volume and are easiest to shell just as the pods begin to turn yellow. For marketing, however, green pods are required; hence, in commercial picking, the pods are gathered before yellowing begins. In southern towns, green Limas are often marketed shelled, though the beans then mold within a few hours. For shipping, and on the larger markets, they are left in the pod and handled as peas. In spite of their very high quality as a fresh vegetable, green Limas are not shipped extensively.

Green Limas for canning are harvested with a bean cutter or a mowing machine, when the majority of the pods are at the ideal green-shelling condition. This method of harvesting gives rather low yields, for many of the pods are small and the "top crop"—pods on the erect raceme, which terminates the main axis of the plant—is not developed. Canning beans are threshed and shelled with a viner similar to that used for peas. Average yields in New York are 1,200 to 1,400 pounds per acre. Valuable by-products are the green pods and plants, which are fed to stock fresh or are ensiled.

Dry Limas are harvested with a bean cutter, field cured, and threshed in about the same way as common beans. Bean "straw" is used as a fertilizer in the citrus orchards of California.

Varieties

There are many varieties of the two main botanical groups of Limas. The following are representatives of the small-seeded type:

Early Carolina (**Sieva, Sewee, Butter Bean**), Pole.

Henderson Bush (**Baby Lima**), Bush.—Much used for canning.

Hopi, Runner Type.—There are strains varying in type of plant and color of seed. The white strains may pass for Hendersons as dry beans. Hopi Limas are especially valuable because of their ability to set pods in a hot, dry climate and because of their resistance to the pod borer.

True, or large-seeded, Limas are divided into two classes, according to the shape of the seed. The flat-seeded class, in which the beans are much compressed laterally, are more or less lunate, with faint veins radiating from the hilum and pods very broad with a distinct point at the tip. The other class is known as the "Potato Lima." It has smaller seeds, more nearly cylindrical or tumid in shape, and pods which are shorter and thicker than in the flat-seeded type.

Of the *large, flat-seeded Limas,* there are four varieties:

Burpee's Bush, Bush.

Early Leviathan (*King of the Garden*), Pole.—Used chiefly for green-shelled beans in the east. Once popular for dry-bean production in California, it is no longer used, because of difficulty in threshing the pods.

Lewis, Medium Pole.—Originating as a single plant selection made by Dozier Lewis at Camarillo, in 1888, this variety now occupies over two thirds of the acreage of dry Limas in California. It is especially adapted to low, moist soils, to coastal locations where early maturity is important, and to irrigated culture.

Dailey, Pole.—This variety was selected by Charles Dailey of Somis, California. It has a larger, more vigorous plant than Lewis, with long, twining stems, and is very productive in the warmer parts of the Lima-bean belt, somewhat removed from coastal influences.

Of the *large, thick-seeded, or Potato, Limas* there are two varieties:

Dreer's Bush Lima and Fordhook Bush.—These varieties are used for green-shelled beans in the northern states and for canning to some extent, but since they are somewhat more tender than the Henderson Bush and require a longer growing season, they are not so dependable in cool regions.

Challenger, Pole.—This is similar in characteristics to Dreer's Bush.

Two other kinds, the Horticultural and the Chickasaw, are often called Lima beans. The former, produced by O. H. Alexander in Vermont, about 1880, was claimed to be the result of a cross between a Lima and a pea-bean but is obviously of pure *P. vulgaris* parentage. The socalled Chickasaw Lima is the Jack bean, *Canavalia ensiformis.* It is grown in the South for stock feed.

Breeding

American varieties of the present day have nearly all been developed by selection within the last 50 years. Cross-pollination occurs to some

extent in Lima beans, according to Halstead (1903), and this no doubt has given rise to many of the new forms. The bush types evidently arose as mutations, since they were unknown until rather recently. The Hopi beans, as grown by the Indians, were much mixed as to color of seed and other characters, but pure lines having constant characters have been isolated by selection.

About the only systematic effort to develop improved varieties of Lima beans is that of Shaw (1913). Over a 4-year period, a selection from the Dailey variety yielded an average increase of 25 per cent over the parental stock. In 50 strains from single plant selections, increased yields of 20 to 160 per cent over the parental variety were secured.

Insects

Pod Borer.—This insect occurs throughout North America and attacks many kinds of beans, but it is especially distinctive on the Lima bean in California. The adult, a small, grey moth, appears in early spring and lays eggs on the pods of beans or of wild lupine. Hatching, the larvae bore through the pod and feed on the developing seeds but do not bore into the seeds, as the bean weevil does. The pods become misshapen, and the seeds are rendered worthless. The larvae attain a length of 1 inch; some of them pupate within the pods, in thin cocoons, while the majority overwinter as pupae in the soil. Holes made in the pods by the entering larvae are still evident at maturity.

The elimination of lupine and of other wild or volunteer hosts and rotation of crops are control measures. All varieties of Limas are susceptible, especially the bush varieties, though the Hopi is rather resistant. The insects are so widely distributed on wild lupine that small plantings of Limas in new localities are often destroyed through the concentration of the insects in a small area (Larson, 1926); whereas, under the same conditions, a large area might show little injury.

Diseases

Downy Mildew (*Phytopthera phaseoli*).—This fungus disease causes extensive losses in humid regions in seasons of heavy rainfall. The fungus is specific to this crop, and all kinds of Limas are affected. A white, downy mold appears in patches on the pods, and the mycelia grow through the pod into the beans. Later, pods and seeds shrivel and turn black. The fungus also appears sparingly on the leaves, young shoots, and flowers. Primary infection takes place from diseased seeds, which do not germinate but propagate the fungus in the soil, whence it reaches the aboveground parts of healthy plants. Rotation of crops, burning dead, diseased plants, and hand picking to remove diseased seeds before planting are important control measures. Beach (1923) reports efficient

control of the disease in Pennsylvania by six applications of copper-lime dust, containing 14.5 per cent monohydrated copper sulphate. Bordeaux mixture was equally effective but not so easy to apply to pole Limas.

Pod Blight (*Diaporthe phaseolorum*).—This disease is also specific to Lima beans and attacks pole more severely than it does bush varieties. Lesions appear first on the leaves, later on the pods. The spots are large, brown and irregular, with rings of black pycnidia. The pods may be completely blackened and wilted. The fungus lives over winter in the seeds and in dead plants in the field. Use of seeds from disease-free plants is the most important control measure. Disinfection of the seeds before planting, by soaking for 10 minutes in mercuric chloride, 1:1,000 parts of water, is recommended.

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CHAPTER XI

PISUM

Peas are grown both for market and for canning. Their importance as a truck crop has increased very much in recent years, as localities have been found for winter production and transportation facilities have become improved. Increase in shipments has been especially striking the last few years.

History.—According to Sturtevant, the pea is native to Europe and northern Asia. He states that

> The pea in India goes back to a remote period as is shown by its Sanskrit name. The discovery of its seed in a tomb at Thebes proves it to have been an ancient Egyptian plant . . . Its culture among the Romans is evident from its mention by Columella, Pliny and Palladius. There is every reason to believe from the paucity of description, that peas were not then in their present esteem as a vegetable and were considered inferior to other plants of the leguminous order.

Peas were introduced into the United States probably early in the seventeenth century. In 1828, Thorburn mentions 24; while in 1883, Vilmorin describes 149 varieties. The canning of peas in the United States was greatly stimulated with the advent of the mechanical huller, which was used here for the first time, about 1887.

Plant Characteristics

Roots and Root Tubercles.—The pea plant has a long tap-root, which, according to Hunn (1922), may grow to a depth of 4 to 6 feet in some types of soil.

The roots support the growth of N-fixing bacteria (*Bacillus radicicola*), which forms upon them abnormal growths called "nodules," or "tubercles." The bacilli are flagellate, rod shaped, and aerobic. Spores are not formed, and its mode of existence in the soil is unknown.

Fred, *et al.* (1926), state that the bacilli move very slowly in the soil if at all, unless carried by the host plant, wind, rain, or tillage operations. Whiting (1915) states that as the tip of the root hair pushes through the soil, it may come into contact with the organisms. These cluster at the tip of the root hair, dissolve the cellulose of the wall, and thus enter the root hair.

The presence of the organism in the tissues of the root causes a rapid cell division in the pericycle. These cells become larger and contain more protoplasm than the surrounding cells, and, as growth takes place, the cortical parenchyma and the epidermis are forced outward, thus forming a nodule. In the central portion of the nodule is the so-called "bacteriodal tissues," which is ochre, flesh, or gray in color, according to the age of the nodule, and in this portion, the infecting strand is distinguished in the young nodule. It ramifies throughout the cells, and those it enters lose their power of cell division but not of enlargement. In older nodules, the infecting strand is not visible, and the bacteriodal tissue loses its firmness. When the host plant is maturing, most of the nodules are soft, and the internal tissues slough off, leaving the more resistant epidermal tissue as a mere shell which decays later.

The bacillus is not very sensitive to the reaction of the medium; it can withstand any degree of acidity or of alkalinity in the soil that the plant itself can endure. Fred, *et al.* (1926), state that the critical PH for the nodule bacilli of the garden pea is 4.7, which is similar to that limiting the growth of the plant.

TABLE 27.—EFFECT OF NODULE BACTERIA ON YIELD OF GREEN PEAS AND GREEN VINES

(*Fred, et al.*, 1926)

Number of experiment	Variety of peas	Increase per acre due to inoculation			
		Green peas after vining		Green vines after vining	
		Pounds	Per cent	Pounds	Per cent
1	Alaska	843	96	4,937	68
2	Alaska	117	7	1,452	9
3[1]	Alaska	−3	..	4,356	53
4	Alaska	1,339	42	9,196	73
5	Alaska	681	35	4,356	47
6	Alaska	767	53	7,260	107
7[1]	Alaska	−0.01			
8	Yellow Admiral	636	14	4,066	21
9[1]	Perfection	887	48	4,550	32
10[1]	Perfection	351	6	4,840	26
11[1]	Horsford	420	11	1,936	12
12[1]	Horsford	97	3	968	8

[1] Peas had grown on these fields before.

Inoculation is usually secured by direct application to the seed of the proper strain of bacteria in pure culture. Seed inoculation is necessary only where the soil does not already contain the organism. On the

Pacific Coast, the soils are generally well supplied with this bacillus; many soils in the Middle West and East, however, seem to lack it. Results obtained by Whiting, *et al.* (1925), in Wisconsin show that inoculation is desirable there even when the land has grown peas previously. In general, they found that inoculation increased the height and the protein content of the vines and made them a darker green. An increase in the yield of vines and peas was also obtained, as shown in Table 27.

Probably the most significant result obtained is the improvement in quality, which is secured by increasing the percentage of smaller sizes of peas and by delaying maturity, *i.e.* keeping the vines in a growing condition longer, thereby giving a longer period for harvesting. It is a good plan to inoculate when peas have not made a satisfactory growth previously. One or two untreated strips should be left beside the inoculated area to determine the difference in growth, yield, and number of nodules on the roots.

Löhnis and Leonard (1926) state that certain strains of nodule bacteria invade the roots of one kind of legume only, while other strains may invade a number of different species. The following crops may be inoculated with the same strain of bacillus: garden pea, Canada field pea, common vetch, hairy vetch, narrow-leaf vetch, purple vetch, broad bean (horse bean), lentil, and sweet pea.

Stems.—Wellensiek (1925) divides all varieties into three groups, according to length of stem: dwarf, 25–90 centimeters; medium-high, 90–150 centimeters; high, 150–300 centimeters. The stems are hollow, and in the tall, the stems are straighter than in the dwarf varieties. Branches often arise from the lower nodes.

Leaves.—The leaves are pinnately compound, with one to three pairs of leaflets; the terminal leaflet and, at times, the upper lateral ones are modified as tendrils. The stipules are large and leaflike. There are two rather distinct shades of green—ordinary and yellowish. Stem color harmonizes with leaf color. Most varieties have a waxy covering, or bloom, over nearly the entire surface of the plant, while others lack this.

Flowers.—The flowers are white and are borne singly or in pairs on elongated peduncles arising in the axils of the leaves. The five sepals are united. The corolla is composed of one standard, two wings, and two united carina-leaves, forming the keel; enclosed by the keel are the ten stamens, nine of which are coherent and the other free. The staminal tube encloses the ovary. There is a single, superior pistil, and the ovary is one-celled. The ovules alternate in a single row on two parallel placenta running lengthwise of the ovary. The extremity of the stigma is pilose on the lower side, forming the style brush. The style is almost perpendicular to the ovary.

Pollination.—According to Müller (1883), there is present in the bud on each side of the conical tip of the keel a pouch in which the anthers are

located. The anthers dehisc shortly before the flower opens. They fill the conical point of the keel with pollen and withdraw into the base of the cone, so that at the beginning of anthesis, the stigma and the style brush are already covered with pollen. Wellensiek (1925) states that the pea plant is seldom visited by insects and is perfectly self-fertile. In the course of 5 years, he found but one case of spontaneous crossing. Many other investigators mention the slight frequency of natural cross-pollination.

According to Wellensiek (1925), in artificial pollination, the lower part of the calyx enclosing the keel is removed or bent aside, after which the carina leaves are parted, so that the interior of the flower becomes accessible. The stamens are then removed. This must be done before the anthers dehisc. If pollen has been shed, the flower is not used. Usually the stigma can be pollinated immediately. As a source of pollen, a flower is chosen which has shed its pollen; the corolla is removed, and the pollen-covered style brush is used to powder the stigma of the mother plant. To assure a good set, pollination is repeated after 2 days. For safety's sake, the pollinated flower is enclosed in a bag of glazed cambric, tied to the peduncle and the top of the bag is tied to the wire netting upon which the plants are growing. About 10 days after pollination, the bag may be removed.

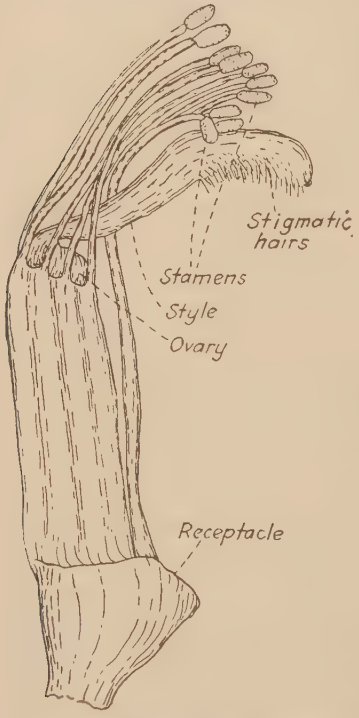

FIG. 36.—Flower of pea with calyx and corolla removed.

Fruit.—The fruit is a pod which, when immature, may be either green or yellowish. Plants with yellowish-green leaves and stems never produce green immature pods. Yellowish-green pods, however, may be borne on plants with either green or yellowish-green foliage. Shippers prefer dark-green-podded varieties, as they appear fresher on the market. The pod is lined on the inside with a parchment-like membrane—the endocarp. In the edible-podded, or sugar, peas this membrane remains soft and pliable, and the ripe pods do not dehisc. In the shelling pea, it becomes hard and dry and causes the pod to split open at maturity. There is also a difference in thickness of pod wall of different varieties. The pod may be curved or straight and blunt or acute at the apex. In some varieties, the pods may reach a length of 18 centimeters and a width of 2.5 centimeters.

Seed.—The seeds are in a single row along the side of the pod and are either wrinkled or smooth. They consist of the embryo enclosed in a transparent seed coat; cotyledons contribute the mass of the seed. According to Gregory (1903), in the round or smooth seeds, the outer cell layers of the cotyledons contain a few oval starch grains, which do not exceed 0.06 millimeters in their greatest diameter. In the third layer of cells, the starch grains reach 0.2 millimeters in length, while the more deeply situated cells are crowded with large, oval starch grains measuring as much as 0.34 millimeters in their greatest diameter. The starch grains are regular in shape, with a definite center surrounded by lines of stratification. In the wrinkled peas, the starch grains of the peripheral layers are of about the same size as those in the smooth peas but are compound and have a tendency to break up into smaller parts. In the deeper-lying cells, these compound grains reach a diameter of 0.18 millimeters or, rarely, 0.2 millimeters. The component grains never reach a length of more than 0.1 millimeters in their greatest dimensions.

The exact relation between the form of the starch grain and the smooth or wrinkled character of the seed was explained by Kappert (1925). He states that wrinkled peas have no compound starch grains, however, but simple ones with splits and that the fact that the latter are formed during maturation of the seed increases the amount of sugar. The wrinkling is due to loss of water in the cotyledons, to which the seed coat cannot conform. This greater loss of water during maturation is also accompanied by a greater absorption capacity for water at maturity. In garden peas, the seed coat is always white or colorless; in field peas, the seed coat may be colored. Mendel (1865) found that the purple-flowered plants had seeds with a gray testa, whereas the white flowered plants had seeds with a colorless testa. The color of the cotyledons may be either green or yellow, although, according to Wellensiek (1925), there is not a well-defined limit between the two groups, neither does a certain variety show a uniform shade of yellow or green; the yellow of the various varieties ranges from greenish yellow to orange. Most varieties have yellow cotyledons. All wild forms have yellow cotyledons, which makes it probable that yellow is the elder color. Some of the cultivated varieties have green cotyledons, the shade of which ranges from yellowish to dark. Unfavorable weather conditions influence the color of the cotyledons. Modifications in color result from insufficient maturing, discoloring after ripening, and injury from insects. Some green forms are apt to variegate. Light will variegate ripe green seed on the exposed side; moisture has a similar effect. Some lines are not homozygous with respect to cotyledon color; such lines are probably the result of crosses in which no notice is taken of this character. Cotyledon color attracted the attention of the early investigators no doubt because when the cotyledon of the male parent is dominant, it can be seen through the transparent testa of

the seeds borne by the mother plant. This phenomenon has sometimes been termed "false xenia."

Time of Flowering.—According to Wellensiek (1925), Tedin of Sweden was the first to point out the parallelism between node number, the number of days from sowing to flowering, and the number of days from sowing to maturity. Tedin, working with a number of varieties, gives the following data to show the relation between these factors:

TABLE 28.—RELATION BETWEEN NUMBER OF NODES IN WHICH FIRST FLOWER IS BORNE AND TIME FROM SEED SOWING TO OPENING OF FIRST FLOWER AND SEED MATURITY
(*Tedin*)

Node number	Average number of days from seed to flower	Average number of days from seed to maturity
9	43.5	91.0
10–12	45.5	102.2
13–15	53.5	109.2
15–17	57.2	116.2
16–18	58.8	116.9
17–19	62.2	119.5
19–20	64.0	113.5
20–22	70.6	122.5
21–23	67.6	123.4
22–24	70.5	122.7
24–25	72.5	128.7

The varieties that produce their first flower on the lower nodes are the first to flower and the first to mature seed. As the number of node in which the first flower is produced increases, the later maturing is the variety. Tedin mentions sowing time as a modifying factor, *i.e.* peas which are sown early will have a longer growing period before flowering starts.

CLIMATIC AND SOIL REQUIREMENTS

Temperature.—The pea is a cool-weather crop. In the South and in California, peas are grown during the fall, winter, and early spring. Young plants endure considerable frost without injury, but the flowers and immature pods are injured by frosts which do not damage the young plant. The round, or smooth, peas germinate under lower temperature conditions than the wrinkled-seeded varieties. The greatest yields are

obtained when the crop matures under fairly cool climatic conditions, which permit rather slow ripening. When the crop matures under high temperatures, the yield is usually lower, the quality poorer, and diseases are more prevalent.

It is a common observation that date of planting is a very important factor in the profitable production of peas. Boswell (1926) planted peas of the Alaska variety at College Park, Maryland, at approximately weekly intervals from late March to early May. Seed planted March 29 required 16 days to appear through the soil, while that sown May 8 was through in 8 days. The peas planted on a certain date were all harvested at one time, as is done for the cannery. As shown in Table 29, the later the planting date in spring, the shorter is the interval between seeding and harvest. Accompaning this is a decrease in the weight of the plant, in the number of pods, and in the weight of pods per plant. In general, as the temperatures increase, the yields decrease. Most of the loss in yield is due to the setting of a smaller number of pods per plant and to a lower weight of the pod. No doubt other factors besides high temperature operate to lower the yield; temperature, however, is by far the most important.

TABLE 29.—INFLUENCE OF TEMPERATURE UPON RATE OF GROWTH AND YIELD OF GARDEN PEA, VARIETY ALASKA, 1926
(*Boswell*, 1926)

Seeded date	Through soil from time seeded, days	First flower from time through soil, days	Mean temperature from date through soil to first flower, °F.	Interval from first flower to harvest, days	Mean temperature from first flower to harvest, °F.	Interval from seeding to harvest, days	Average weight of plant, grams	Average number of pods per plant	Average weight of pods per plant, grams
March 29	16	29	59.39	29	64.73	74	22.57	4.28	12.95
April 3	13	28	60.39	28	64.62	69	25.92	4.87	14.53
April 9	12	26	63.07	28	66.09	66	21.84	4.11	12.49
April 16	12	24	63.31	27	66.06	63	22.25	4.08	11.69
April 24	11	23	63.91	28	65.61	62	20.92	4.40	10.61
April 30	8	22	64.03	23	68.33	53	17.45	3.25	7.59
May 8	8	21	63.34	22	70.50	51	13.18	2.51	6.46

Kotowski (1922), in Poland, planted peas at 20-day intervals, as shown in Table 30. The flowers were labelled at time of anthesis, and the pods were harvested after 14 days. As the temperature became higher, the rate of ripening increased, as is evidenced by the heavier weight of seeds harvested later in the season.

TABLE 30.—INFLUENCE OF TEMPERATURE ON RATE OF RIPENING. ONE HUNDRED PODS USED FOR EACH SAMPLE, VARIETY MAI ERBSEN, 1921
(*Kotowski*, 1922)

Date sown	Ripening period		Fresh weight, grams	Dry weight, per cent	Percentage of dry weight			Ratio, protein nitrogen: total nitrogen
					Total nitrogen	Protein nitrogen	Ash	
Apr. 12	Flowers labelled, May 23	Seed	65.2	14.4	7.00	5.20	6.63	0.74
	Pods harvested, June 6	Pod	236.8	16.4	5.45	3.83	6.06	0.70
May 2	Flowers labelled, June 6	Seed	112.5	17.2	5.80	4.18	4.50	0.72
	Pods harvested, June 20	Pod	302.0	17.2	2.65	2.00	4.90	0.77
May 23	Flowers labelled, July 1	Seed	120.8	18.2	5.80	4.15	4.18	0.71
	Pods harvested, July 14	Pod	300.4	17.5	2.98	1.80	5.18	0.60

Soil Preferences.—Peas succeed on a variety of soil types, if the latter are well drained. Clay and silt-loam soils are especially suitable, as they are retentive of moisture, cool, and usually more fertile than the lighter soils. Heavier soils are used usually for production of the canning crop and for seed. The crop usually matures early on soils of a sandy nature, and the latter are often used for the production of the early market-garden crop.

PRODUCTION

Peas for Canning.—Most of the canning peas are grown in Wisconsin and New York, but Michigan, Illinois, Utah, Maryland, Indiana, Ohio, and Minnesota can a considerable quantity.

According to Shoemaker (1922), a good canning variety must meet certain requirements: It must be productive. This will therefore exclude the very dwarf types; all plants must ripen uniformly; all pods on the individual plants must be in a usable condition at one time, *i.e.* there must not be any too ripe or too immature; this requirement tends to exclude tall varieties; the seeds should remain green after processing. This requirement relates to appearance only, since it is not claimed that the green-seeded peas are of higher quality, but peas with yellow cotyledons therefore cannot be used; and high edible quality. This is the most important requirement, and there is much difference between varieties in this regard. In any variety, to obtain high quality, the vines must be harvested before the seed is overmature, and the latter must be processed soon after harvest to prevent loss of sugar.

The Alaska is at present the leading canning variety. It is hardier and a more reliable cropper than the wrinkled varieties, so that in the southern part of the canning region, it is the only variety used. Even in Wisconsin, Michigan, and New York, where the climate is more congenial to this crop, a large acreage of Alaska is planted, because it matures and

may be packed before the earliest wrinkled varieties. The season for packing peas is thus lengthened, a fact very important from the packer's standpoint. The Alaska is deep green and retains its color after processing. The leading wrinkled variety of pea used for canning is the Horsford; the Advancer and Admiral come next in importance, and a few other varieties are used to a lesser extent. The Horal variety recently introduced by the Wisconsin Agricultural Experiment Station does well in some sections; according to Delwiche and Renard (1926), it seems to be somewhat resistant to root rot.

In the main canning areas of the North, Middle West, and East, the crop is usually sown in early spring. Where climatic conditions are favorable, the crop may be sown in the late fall or winter. Successive plantings are often made, so that the entire crop will not mature at the same time. Seeding is usually done with a grain drill or special pea seeder.

The crop is harvested when most of the pods are well filled with young, succulent peas and the color is changing from dark to light green. The aim is to harvest the crop at a time when the maximum yield will be secured and at the same time to obtain grades of high quality The crop is usually cut with an ordinary mowing machine, fitted with vine-lifting guards and swather. The vines are loaded onto racks and hauled to the cannery or a field vining station. The peas should be canned as soon as possible after the crop is cut as deterioration is rapid, especially under high-temperature conditions.

In many sections, after threshing, the vines are ensiled by placing them in silos or large stacks in the open. The ensilage is very palatable and makes pea growing for the cannery and dairying a good combination.

Peas for Market.—Those states important in the production of green peas for market are New York, North Carolina, New Jersey, Colorado, Mississippi, California, Arizona, South Carolina, and Virginia. The west coast of Mexico is now also an important shipping district. Wrinkled varieties are used almost exclusively. In California, Laxton's Progress, Laxtonian, and Dwarf Telephone (Carter's Daisy) are the three most popular varieties for shipping, while in many of the eastern states, Gradus and Thomas Laxton are very popular. For shipping and the market garden, dwarf varieties are in general use. The tall varieties are grown mainly in the home garden.

Germination.—Kotowski (1926) planted pea seed of Blue Bantam, a wrinkled-seeded variety, 4 centimeters deep in quartz sand at constant temperatures ranging from 4 to 30°C. As shown in Table 31, all the seed germinated at 18°C. A decrease in the percentage of germination was obtained at higher or lower temperatures.

Jones (1912) found that the cotyledons of the ripe seed are filled with starch and that during germination, the digestion of starch begins

TABLE 31.—GERMINATION OF PEA SEED AT DIFFERENT TEMPERATURES
(*Kotowski*, 1926)

Temperature, °C.	4	8	11	18	25	30
First seedling, days after sowing	35	14	10	4	3	3
Last seedling, days after sowing	46	23	16	6	5	5
Seedlings in per cent of seed sown	84	87	88	100	82	70

in the peripheral cells on the convex side of the cotyledons. A short time later, digestion starts in the outer cells of the flat face. The removal of the starch gradually proceeds inward toward the vascular bundles. The enzymatic action at any one time seems to be confined to a layer two or three cells in thickness, from which the starch is almost completely removed before any marked amount of digestion takes place in the adjoining cells nearer the center of the cotyledon. The starch is removed finally from the entire cotyledon, except that usually a few isolated groups of cells retain their starch without any apparent change. Injured cells also retain their starch. Kidd and West (1919) found that soaking pea seeds in water is injurious, the number and vigor of the plants being lowered. Injury is more marked at low temperatures (5 to 10°C.) than at medium temperatures of soaking (15 to 20°C.). At higher temperatures, the amount of injury again increases, as is shown in Table 32.

TABLE 32.—EFFECT OF SOAKING ON GERMINATION. SEEDS SOAKED UNDER 4 CENTIMETERS OF DISTILLED WATER, SOWN TOGETHER WITH THE UNTREATED CONTROLS, IN COOL GREENHOUSE IMMEDIATELY AFTER SOAKING TREATMENT, TWENTY-FIVE SEEDS USED IN EACH EXPERIMENT, VARIETY SUTTON'S MAINCROP
(*Kidd and West*, 1919)

Period of soaking, in hours		0	24				48				72			
Temperature of water used, °C.		..	5	10	20	30	5	10	20	30	5	10	20	30
Number of germinations after	7 days	17	5	9	13	11	2	8	9	6	1	4	5	1
	14 days	18	5	9	13	9[1]	2	9	10	7	1	4	7	1
	21 days	18	5	10	14	9	3	9	10	7	2	4	7	2
	28 days	18	5	10	14	9	3	9	10	7	2	4	7	2
	35 days	18	5	10	14	9	3	9	10	7	2	4	7	2

[1] Two died.

The most plausible explanation of the injury is probably that essential soluble-food reserves and enzymes are leached out. According to Jones (1912), the starch-digesting enzymes are much more active in the peripheral layers of the cotyledon than in the more deeply lying cells. These may be leached out when the seed is soaked, thereby destroying the viability or reducing the vigor. In Table 33, Kidd and West (1919) show that there is considerable leaching taking place.

TABLE 33.—EFFECT OF VARIOUS TEMPERATURES ON EXOSMOSIS OF SOLUBLE SUBSTANCES IN EXCESS OF DISTILLED WATER, VARIETY SUTTON'S MAINCROP; SEEDS SOAKED 3 DAYS UNDER 4 CENTIMETERS OF DISTILLED WATER, FIFTY SEEDS USED IN EACH EXPERIMENT
(*Kidd and West*, 1919)

Temperature of water used, °C	5	10	20	30
Total weight of solid matter leached out of 50 pea seeds during experiment	0.278	0.253	0.220	0.659

Chemical Changes during Ripening.—Boswell (1924) studied the chemical changes taking place in seed during the growing and ripening period. Flowers were labelled when they were open. Pods of the same age were collected at definite intervals for analysis. The varieties used were Alaska and Nott's Excelsior. Table 34 shows that as the seeds increase in age, there is a rapid decrease in sucrose and soluble N but an increase in dry matter, starch, total polysaccharides, and insoluble N.

TABLE 34.—CHANGES IN CHEMICAL COMPOSITION OF GARDEN PEAS DURING RIPENING, VARIETY NOTT'S EXCELSIOR, AMOUNTS EXPRESSED IN PERCENTAGE OF DRY WEIGHT
(*Boswell*, 1924)

Year	Age in days	Dry matter	Reducing sugars	Total sugars, as sucrose, per cent	Starch, per cent	Total polysaccharides, per cent	Insoluble nitrogen, per cent	Soluble nitrogen, per cent	Total nitrogen, per cent
1924	14	17.48	Trace	35.17	0.0	32.82	1.83	2.47	4.30
	16	20.36	Trace	33.72	8.75	39.67	2.35	1.56	3.92
	19	24.97	Trace	20.02	16.13	67.35	3.20	0.78	3.98
	22	30.35	Trace	9.60	21.35	82.16	3.32	0.56	3.89

The variety Nott's Excelsior had the pods well filled and was in the best stage for harvest on the fourteenth day. After this time, there is a rapid loss of sucrose and an equally rapid gain in polysaccharides. The loss in edible quality of the garden pea is probably due in the main to the change of sucrose to starch.

The pods are harvested when well filled and while the quality is still good. They are picked by hand; usually two or three pickings are made.

Peas are usually packed in crates or hampers for shipment. Ice is usually placed in the package; but for short-distance shipment, ice is placed in the bunkers only. Peas deteriorate in quality very rapidly, especially at high temperatures, and should therefore not be allowed to heat in the container or when stored at high temperatures.

Shipping Season and Carlot Movements.—Most of the green peas shipped in the United States move from March to November. Most of the crop from Central California is shipped during April, May, and October, while the fall crop from the Imperial Valley is shipped chiefly during November and December; and the spring crop, during March and April. Mississippi ships mainly during April and May; New York, during June, July, and August; North and South Carolina, in April and May; Virginia, in May and June; and Washington, in June and July. During the winter months, December to March, a considerable quantity of peas is imported from Mexico; in 1926, this amounted to 607 carloads.

TABLE 35.—SHIPPING SEASON AND CARLOT SHIPMENTS OF GREEN PEAS, 1925–1926

State	Shipping season	1925 (April to December)	1926[1]
Arizona	March to May	14	19
California, northern division	April to November	8	6
California, southern division	April, November	7	
California, central division	March to November	208	428
California (Imperial Valley)	October to April	346	364
Colorado	July to September	35	59
Idaho	August	13	41
Maryland	May to June	48	55
Mississippi	April to May	149	294
New Jersey	June	20	25
New Mexico	August to October	1	59
New York	June to September	885	1,109
North Carolina	April to June	491	106
South Carolina	April to May	104	168
Tennessee	April to May	18	30
Virginia	April to June, October	303	285
Washington	May to July	43	64

[1] Subject to revision.

TABLE 36.—CARLOT SHIPMENTS OF GREEN PEAS BY MONTHS FOR UNITED STATES

	January	February	March	April	May	June	July	August	September	October	November	December	Total
1925 (April to December)	..	..	...	425	821	267	619	201	29	23	228	94	2,707
1926 (April to December)	4	13	115	250	826	241	890	306	101	108	234	45	3,133

BREEDING

Many of our varieties of garden peas originated in England. Peas are used to a greater extent by the average family in England than in

America, and consequently the English have given more attention to this crop's improvement. Their climate is very congenial to it.

Thomas Laxton of Bedford, England, has probably introduced more varieties than any other individual. As early as 1889, he had introduced about 50 varieties. Many of these are still among our leading sorts. Most of the varieties introduced by him were the result of crosses and the selection of desirable individuals among the progeny. Laxton states that his chief endeavor has been to secure earliness, increase in size, a well-filled pod, and improvement of quality as well as the production of later varieties. As early as 1889, he stated the need for large pods and medium-short, jointed stems, which produce freely at each joint from the ground upward. He emphasizes especially the need of pods of a deep-green color, because they command a higher price. Since 1889, additional varieties of merit have been added to his long list of introductions.

From the time of Mendel, the pea has been used constantly to study the mode of inheritance of different characters. A few of the results obtained are as follows: Thin is dominant over thick pod wall; green is dominant over yellowish-green foliage color; glaucous is dominant over non-glaucous foliage; green is dominant over yellowish-green pod color; tall is dominant over dwarf and also over medium-tall stem; smooth are dominant over wrinkled seeds; grey are dominant over colorless seed coats; yellow is dominant over green cotyledon color. In all of the above cases a 3:1 segregation is obtained in the F_2.

Data presented by Bushnell (1921) show that strains derived from single plant selections of the Alaska pea possess measurable differences in yield and that these differences are of a genetic nature. Most seedsmen are also of the opinion that improvement can be made by single plant selections; the majority of the commercial stocks of peas being grown by the American seedsmen have been derived from single plants. This process of developing new lines is continuous with most seedsmen. From the single plant it takes 6 to 8 years of increase to obtain the first commercial crop of seed.

Seed-pea Growing

The growing of seed peas for the canning and market-garden trade is an extensive enterprise. A large acreage must be planted in order to maintain the commercial acreage planted by the canners and market gardeners.

Areas of Production.—Most of the seed peas are now grown in the irrigated regions of the West. The main producing regions at present are the Bitter Root Valley and the Gallatin Valley of Montana, the Upper Snake River Valley of Idaho, the Palouse region of eastern Washington and western Idaho, the Sacramento Valley, Napa County, and the coastal

regions near Salinas. Watsonville, and Half Moon Bay in California. In Wisconsin, the penninsula between Lake Michigan and Green Bay has also been an important producing center.

Sowing.—In the Sacramento Valley of California, the seed is usually sown during the winter, but along the coast and in all other sections, the crop is usually planted in the spring. Seed is ordinarily sown with a bean drill at the rate of about 80 to 100 pounds to the acre and in rows 24 to 30 inches apart. In some regions, peas for seed are planted with a grain drill or broadcast.

Rogueing.—It is the aim of the seedsmen to supply high-quality seeds to the canners and market gardeners. Even when great precautions are taken to prevent warehouse mixtures and when crop rotation is practiced to prevent the appearance of volunteers, it is necessary to go over the fields a number of times to pull out the off-type plants; this process is known as "rogueing" and the off-type plants, as "rogues." Rogueing may be done when the plants are small, in bloom, or maturing. Plants are rogued when they are off type in habit of growth, shape, size, or color of leaf; in color of flower or in size, shape, or curvature of pod. The most difficult of all rogues to remove is probably the one which differs only in pod characters. The "rabbit-ear" rogue is one of the most common ones, and it appears constantly in some varieties. This is characterized by very small, narrow leaves and stipules. Usually, all seed fields are rogued, but most care is used in the multiplication plots and in the stock fields.

Harvesting, Threshing, and Handling.—The seed fields are usually cut when the seeds are beginning to get hard. If harvesting is delayed too long, there is a heavy loss from shattering. The vines are usually cut with a mowing machine equipped with pea guards and a "curler." The guards lift the vines off the ground and facilitate cutting, while the curler moves the vines out of the way of the horses and mower. Men follow the mower and put the vines in small bunches to cure. Threshing is usually done directly from the bunch, by use of an ordinary grain separator especially equipped for peas. After threshing, seed is delivered to the warehouse, where it is fumigated if grown in weevil-infested territory. It is then run through cleaning machines, which remove cracked and split peas and foreign material and grade the good peas to uniform size. The seed is finally hand picked to remove those damaged, not true to type, or otherwise undesirable.

Diseases

Anthracnose.—As far as is known, anthracnose of the garden pea occurs in this country only in Wisconsin. Jones and Vaughan (1921) state that it

. . . occurs upon all aerial parts of the plant, and although it has not been detected upon the seed itself, there is no apparent obstacle to the penetration of seeds in diseased pods. Upon leaves, the lesions are irregular in shape, smoky gray or brown toward the margin, and lighter in color, usually tending toward a brown at the center. On pods they are usually lighter in color, more nearly circular in shape, and dark brown at the margin. On stems, the lesions are elongate, rarely encircling the stem, and when covered with spores are ashen when dry and copper color when moist. Setae are sometimes produced so abundantly upon stems that they can be seen with a hand lens. On stems that are nearly mature, the fungus may produce in moist weather rusty areas of considerable extent when spores are produced in tiny acervulus.

Powdery Mildew (*Erysiphe polygoni*).—Powdery mildew is probably distributed throughout the world. Upon the host, the fungus forms a dense, persistent mycelium, frequently covering stems, leaves, and pods. It is recognized by the whitish or grayish coating on all parts of the pea plant, especially late in the season. The conidia are produced in profusion; they germinate at once, causing secondary infection. The perithecia are produced in abundance, especially after the plants have begun to dry up. Within the perithecia are produced the ascospores. These live over winter and infect the crop the following spring.

Control.—Powdery mildew can be controlled by use of Bordeaux, but the most common method of control is dusting with S. As the mildew is most destructive during warm weather, it is best, in regions where mildew is severe, to seed early or to plant quickly maturing varieties. When peas are grown as a market-garden or truck crop, the vines should be turned under soon after harvest to prevent the production of the overwintering perithecia.

Root Rot (*Aphanomyces euteiches*).—Within the last few years, root rot has become increasingly destructive, especially in the central and eastern United States. It has also been found in Utah, Idaho, Montana, and California. While the fungus attacks the subterranean portion of the plant only, it is usually not until the aerial portion is modified that the presence of the disease is recognized. According to Jones and Drechsler (1925), if the plant is invaded in the stem below ground and in the roots before three or four nodes are developed, sudden wilting may result. Usually, invasion takes place later than this and results in retarded growth and death of the lower leaves progressively upward, and when the plant is in full bloom, it may shrivel up completely or remain in a weakened condition until the poorly filled pods reach maturity.

If extensive infestation of the roots is delayed until blossoming, the plant matures under favorable conditions without any conspicuous indication of injury. If pulled, the stems of those which are thoroughly invaded do not break at the seed, as is the rule with healthy plants, but the vascular core of the tap-root and of a few laterals will be pulled out.

This test does not apply in the earlier stages of the disease and sometimes fails when the soil is hard and dry. There is a soft decay and shrinking of the cortex of the roots and of the stem below ground. After a time, the dead cortical tissue usually becomes blackened. The spores of the fungus are always formed more or less abundantly in the dead cortex of the root or in the stem.

The fungus is mostly intra-cellular. Oogonia and antheridia appear when the cortical tissue begins to collapse, and oospores are produced. Infection may take place between 10 and 30°C., but the optimum temperature for the development of the disease is between 15 and 30°C.

Control.—Root rot seems to be most destructive on poorly drained soils or those very retentive of moisture. Good drainage and crop rotation will no doubt help to keep the disease under control, though Linford (1927) states that this fungus may live as a weak parasite on a wide range of host plants, a fact which makes complete control by crop rotation difficult. In the case of peas, however, it is often desirable to grow the crop in short rotation or on the same ground for a number of years. For this reason, then, resistant varieties should be developed. This work is now in progress at the University of Wisconsin.

Pythium.—According to Jones, *et al.* (1926), several species of Phythium are capable of attacking pea seedlings. A soil temperature of 16°C. or above is necessary for seedling attack, and if planted sufficiently early, the plants are past the susceptible period before this temperature is reached.

Rhizoctonia.—Rhizoctonia injury is restricted to seedlings or very young roots. It may attack the germinating seeds and destroy the embryo or, in later or less severe attacks, destroy only the growing points of the roots or stem. The stem tissues soon become resistant to infection, but root-tip injury may continue after the plant is well established. Rhizoctonia requires low temperature for parasitic activity, attacking seedlings at a temperature as low as 9°C. It does its maximum injury at 18°C., and may develop to a less serious degree through a still higher range up to 29°C. The minimum temperature is below that of the major pea-root parasites, hence Rhizoctonia injury may occur early in the spring (Jones, *et al.*, 1926).

Mosaic.—Mosaic of the garden pea is probably widely distributed in this country, although it has not been reported extensively. Doolittle and Jones (1925) studied it in Wisconsin. They state that there is a distinct mottling of the leaves in most cases, due to the presence of numerous small, dark-green areas between the larger veins. These dark areas are irregular in outline and seem usually to follow the small veinlets, but there appear to be also some of the large, green areas which occur in tobacco mosaic. Where plants have been diseased for some time, the dark-green portions of the leaves may be replaced by yellowish-green

areas, which are of similar size and outline but lighter in color than the rest of the leaf. The curling, wrinkling, and general deformity of the leaf, which occur in mosaic of sweet peas and in other plants, are mostly absent.

Mosaic pea leaves are usually of a lighter green than those of normal plants. They are somewhat smaller, and occasionally there is slight curling of the edges of the younger leaves. Symptoms appear most pronounced in the later varieties, which have a luxuriant growth. The plants may be dwarfed, particularly if infected when small. In such cases, the pods appear to be smaller and fewer than those of healthy plants of the same varieties. The incubation period of the disease seems to vary from 6 to 14 days. Doolittle and Jones (1925) showed the possibility of artificial inoculation with juice from mosaic plants to healthy plants by pea aphis. Sweet-pea and red-clover mosaic is transmissible to the garden pea. There was no evidence of seed transmission. Probably the best means of mosaic control is to keep down aphis attack.

Insects

Pea Aphis (*Nectarophora pisi*).—The pea louse is reported as a destructive pest in almost every locality in which peas are grown. The winged lice are from $\frac{1}{8}$ to $\frac{1}{7}$ inch long; their bodies are mostly of a pea-green color, and they are light yellowish brown between the wings and on the head. Sanderson (1920) reports that the pea aphis in Delaware passes the winter preferably upon crimson clover. About May 1, winged females go to the peas, upon which they deposit 110 to 120 young, which develop into wingless, viviparous females. These, as well as the subsequent broods, produce living young. Winged lice develop when the host plant becomes overcrowded, making migration necessary. About 12 days are required for a louse to reach maturity. During midsummer, the lice are nearly exterminated by predaceous insects and disease; but in September, they again increase in number. Folsom (1909) reports that the pea aphis in Illinois overwinters both as a large, wingless, viviparous female and as an egg but that eggs are not numerous.

Aphis damage the plant by sucking its juice. At first, they accumulate on the young growing tips and on the flowers and young pods, but eventually they cover the entire plant.

Control.—Folsom (1909) mentions a fungus parasite (*Empusa aphidis*) as the most important enemy of this louse. The fungus does not occur in dry weather but is abundant during warm, moist weather. Predaceous insects also help keep the pest under control. Smith (1914), working in Virginia, states that clover, especially crimson clover, should not be grown in the vicinity of pea fields, as the aphis pass approximately 8 months of the year on it. He recommends spraying with a solution of 10 ounces of Blackleaf 40 (nicotine sulphate), 4 pounds of

whale-oil soap, and 50 gallons of water or with a solution consisting of 5 pounds of soap only in 50 gallons of water. Beginning when the aphis are first found on the vines, several sprayings may be necessary to obtain complete control. In some sections, good control has been obtained by the use of 10 per cent nicodust. By the use of nicosulphur, the mildew can also be controlled. When a power duster is used, a long canvas trailer attached to the machine holds the dust about the plants and increases the efficiency of the spraying. If epidemics of aphis are expected, it is best to sow seed in rows sufficiently far apart to permit the use of power machinery. Because of the high percentage of nicotine required and the consequent cost, this method of control can be used with profit only where especially high returns are obtained.

The Pea Weevil (*Bruchus pisorum*).—According to Chittenden (1898), the pea weevil occurs wherever peas are cultivated. It does little damage in the colder regions, however. The adult is about 5 millimeters long and 2.5 millimeters wide, black in color and covered with brown pubescence or variegated with black and white markings. The abdomen projects beyond the wing covers, is covered with a whitish pubescence, and marked by two black spots. The egg is about 1.5 millimeters long, yellow, and has one end pointed and the other blunt. The larva is nearly cylindrical, fleshy, strongly wrinkled, and perfectly white throughout, except for the mouth parts, which are brown. The full-grown larva is about 6 millimeters long. The pupa is white.

The eggs are deposited singly upon the surface of the pod. On hatching, the larva bores through the pod walls and enters the developing seed. It feeds and then pupates within the seed. Pupation requires 9 to 17 or more days, depending upon the temperature. In the North, the adult beetles remain in the seed over winter and are planted with it, while in the South, they leave the seed in July or August. According to Sanderson and Peairs (1921), in large peas about one sixth, while in smaller ones, fully one half of the food content is destroyed. Only 12 to 18 per cent of the infested seed will produce plants, and these are later in developing and do not yield as well as those uninjured.

Control.—The Baltimore oriole has been reported as feeding on the larva by splitting open the pods, and the crow blackbird is said to devour many of the beetles. Fletcher (1905) states that fumigation with carbon bisulphide kills all stages of pea weevil in stored seed. For the treatment of small quantities of seed, small air-tight containers may be used. To treat 300 pounds of seed, 3 ounces are sufficient. The seed should be fumigated as soon as possible after harvest, to check the damage of the weevil. Treatment may be given any time the temperature is above freezing. Where large quantities of seed are treated at once, 1 pound of carbon bisulphide to every 100 bushels of seed is the amount generally used. The exposure should be 48 hours.

Pea Moth (*Laspeyresia nigricana*).—The pea moth, as far as is known, is present in this country only in Wisconsin and Michigan. It has been a pest in Canada since 1893 and is probably present in most European countries. It attacks most varieties of both garden and field peas. According to Fluke (1920), the eggs are slightly smaller than a pinhead, flat, and slightly oval in shape, whitish, nearly transparent when first laid, and usually deposited singly upon the pods, leaves, or stems. They hatch within from 7 to 10 days. The young larvae eat their way through the pod and feed upon the seeds. There is usually just one larva to a pod. Growth is completed in from 16 to 26 days. When full grown, the larvae are about ½ inch long and yellowish white in color. They leave the pods and enter the soil and construct a strong cocoon. In Wisconsin, the insect spends 10 months of the year in the cocoon. In late spring, the insect changes to a pupa, the adults appear shortly after the vines have started to bloom. The moths are about 5/16 inch long and slightly less than ½ inch wide when the wings are spread. They are mouse-colored, with 16 to 18 black and white oblique dashes along the foremargin of the front wings. They are most active between 4 to 8 p.m.

Control.—The methods of control advocated are (1) planting of early maturing varieties, (2) early planting, (3) plowing deeply in the fall to destroy hibernating larvae, and (4) thorough soil tillage.

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PART VII

MALVACEAE

The only members of the mallow family grown as vegetables are okra (*Hibiscus esculentus*) and roselle (*Hibiscus sabdariffa*).

CHAPTER XII

HIBISCUS

SECTION A. OKRA

Throughout the South, okra is a popular vegetable for local use, but is scarcely used at all in the North and West. Considerable quantities are grown in New Jersey, where it is canned as one ingredient of soup. Some dried okra is imported for the use of Turkish people in America.

Taxonomy and History.—Okra is a close relative of cotton (*Gossypium sp.*). The cross, okra × cotton, has been obtained at the Georgia Experiment Station (1892) with the production of viable seeds. These yielded okra plants like the ♀ parent but later in flowering and fruiting, suggesting parthenogenetic origin. The reciprocal cross, cotton × okra, resulted in non-viable seeds.

Okra is native to the Old World tropics and was probably first used as a food in equatorial Africa. It seems to have been introduced into the United States along with African slaves, under the name "gumbo." According to Sturtevant, it was used as a food in Egypt in A. D. 1216 and was well known among the Spanish Moors. In 1863, Burr described four varieties as grown in American gardens, two dwarfs, one tall and white podded, and one tall with pendant pods. The last has disappeared, but the others are still grown.

Plant Characteristics

The okra plant is a tender annual, although it may grow for 2 years in frost-free regions. In form and branching habit, it resembles the cotton plant. The cylindrical stems become woody with age. Several lateral branches arise from near the base of the main axis and assume an erect position. When the terminal bud is destroyed, stem elongation is never resumed through growth of axillary shoots from the upper part of the stem. The leaves are ovate in outline and are variously lobed; they are covered with stiff hairs, which are very irritating to the hands of the pickers. The flowers occur singly, in all the leaf axils of the central stem and branches. They form progressively from the base toward the top at the rate of one per day on each stem, when the plants are growing rapidly. They are large and showy, perfect, and mostly self-fertilized, though some crossing does take place through insect visitation. The stamens form a column about the pistil and are anther-bearing along their

entire length. The fruit consists of an elongated, ribbed, hairy pod. The pods become 4 to 12 inches long and are hard and woody at maturity. When dry, they dehisce along the sutures, scattering the seed. The color of the immature pods varies from deep green to nearly white in different varieties, and the degree of ribbing varies also. The pods are at the best edible stage when about half grown. As they become older, their walls become hard and fibrous; the test for edibility is the ease with which they may be cut with a sharp knife. They are harvested by severing the peduncle just below the pod. Picking is done every 36 to 48 hours when the pods are developing rapidly. Okra exhibits a marked correlation between vegetative growth and seed formation. When pods are allowed to mature on the plants early in the season, stem elongation and flowering soon ceases, whereas when the young pods are harvested regularly, stem elongation and fruiting continue until the plants are killed by frost.

Climatic and Soil Requirements

Okra requires a long, warm growing season. The seeds do not germinate below 20°C., the optimum temperature for germination being about 30°C. In the North, a plant may produce only a few pods, whereas in the South, 150 to 200 pods may be produced. In the interior valleys of California, okra thrives fairly well. Soils for this plant should be well supplied with moisture and nutrients.

Varieties

There are two general types of okra. Dwarf varieties have short internodes, grow about 3 feet high, and have short, thick pods. Tall varieties have long internodes and grow 8 to 10 feet high.

Long Green.—This is the most popular variety. The plants are tall; the pods are long, slender, dark green, and five-angled.

White Velvet.—This variety is not so productive as Long Green, because of longer internodes and fewer pods. The plants are tall; the pods are long, cylindrical, and pale, greenish white. The type is often referred to as Lady Finger, although a dark-green-podded type also goes under this name.

Dwarf Prolific.—The plants are dwarf; the angular pods are 3 to 4 inches long and nearly half as thick.

Several other types, imported from North Africa and Turkish countries, where okra is a very popular vegetable, have been described by Beattie (1905).

Diseases

Wilt (*Verticillium albo-atrum*).—This is a true wilt disease, caused by the ubiquitous soil-infesting fungus, Verticillium, the same species of

which also attacks cotton and many other plants. A similar wilt disease of okra, distinguishable only by culturing the organism, is caused by *Fusarium vasinfectum.* Verticillium occurs chiefly in Virginia and New Jersey, in the northern range of okra production, while Fusarium, which requires higher soil temperature, occurs farther south. Wilt diseases are readily recognized by the drooping of the plants and the discoloration of the vascular tissue. Since the organisms causing wilt survive in the soil, rotation with non-susceptible crops should be practiced. Neither kind of wilt is transmitted in or on the seed.

SECTION B. ROSELLE

Roselle belongs to the same genus as okra and even more closely than okra resembles cotton in plant and flower characteristics. It is an annual tropical plant the edible part of which is the thickened calcyes surrounding the seed pod. These are ready for picking about 3 weeks after the flowers open. The latter are borne singly on the axils of the reddish, profusely branching stems. Roselle is grown rather extensively in India and northern Australia and has been introduced into the frost-free portions of the United States. The fruits are used for making jam and jelly; the plants are valuable also for the fiber obtained from the stems.

Regardless of the date of planting, roselle does not flower or fruit in the Northern Hemisphere until the short days of December, thus exhibiting marked photoperiodism. McClelland (1924) showed that when the length of daily illumination was shortened to 11 hours, the plants began flowering promptly. Plants given a daily illumination of 13½ hours for 5½ months grew tall without any tendency to flower. Hence, production of roselle for the fruits in temperate zones is not practicable, unless frost-free conditions enable the plants to grow through December. On the other hand, it might be grown as a short-season crop in northern latitudes, if the length of day were artificially shortened to 11 hours.

Pollination and the inheritance of many characters have been studied by Howard (1911). The flowers are self-fertile and cross-pollination is rare.

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PART VIII

UMBELLIFERAE

The umbellifers have received their name from the shape of the inflorescence. Some members of this family are grown for their food value; others, for essential oils used in seasoning. The two most important crops of this group are carrots (*Daucus carota*) and celery (*Apium graveolens*). The former is grown for its fleshy roots and the latter, for its petioles. Parsnip (*Pastinaca sativa*), celeriac (*Apium graveolens* var. *rapaceum*), and parsley (*Petroselinum hortense*) are other crop plants of this family, which are grown to a limited extent only. Umbelliferae were used very much by the ancients for medicinal purposes.

The carrot is a very popular home-garden vegetable, and is grown to a considerable extent as a market garden crop and to some extent in the South and California as a truck crop.

CHAPTER XIII

DAUCUS

History.—According to Sturtevant, the carrot is a native of Europe and adjoining parts of Asia. The wild carrot, an annual, is thought to be the ancestor of our cultivated varieties, which are biennials. Vilmorin (1840) of France, working with this, was able to obtain the biennial form and made considerable improvement in the root by selecting for several generations. The carrot was probably cultivated by the ancients, although there is almost no record of it. The cultivated plant is mentioned as being grown in Virginia in 1609 and in Massachusetts in 1629; both the cultivated and the wild carrot now grow throughout a large part of the world.

Plant Characteristics

The cultivated carrot is generally biennial. During the first year, a rosette of leaves and a large tap-root are formed; the second year, the flower stalk and seeds are produced.

Roots.—The fleshy "root" develops from hypocotyl and primary root. The hypocotyl region is free from fibrous roots. In cross-section, from outside to center of the root, the tissues are: the periderm, cortex and phloem, cambium, and the central region, or wood and pith. The best-quality carrots are those which have a thick cortex compared to the central region. Four rows of lateral roots arise from the tap-root. Thompson (1920) states that the tap-root and some roots arising from the side of the carrot reach a depth of 30 inches and are much branched. Directly beneath the plant, the soil was well filled with roots to the depth of 25 to 30 inches. The main storage products are sucrose and invert sugars.

Stem.—The portion between the tap-root and crown develops from the hypocotyl, while the platelike stem, from which the rosette of leaves arises, develops from the plumule. During the second year, the stem elongates and forms rough and hispid branches 2 to 4 feet high, with large nodes and hollow internodes.

Leaves.—Most of the leaves have long petioles, which are expanded at the base. The leaves are pinnately decompound; the segments are linear or lanceolate, dentate, and lobed or pinnatifid.

Inflorescence.—The inflorescence is a terminal compound umbel, *i.e.*, consists of a large number of umbellets. The umbel is subtended by a

number of long-lobed, involucral bracts. The umbellets are subtended by involucels, with entire or toothed lobes. When approaching maturity, the peduncles of the outermost umbellets bend inward, giving the umbel the appearance of a bird's nest.

Flowers.—The flowers are perfect, or polygamous, small, whitish, and numerous. The central flower of each umbel is often purple. The

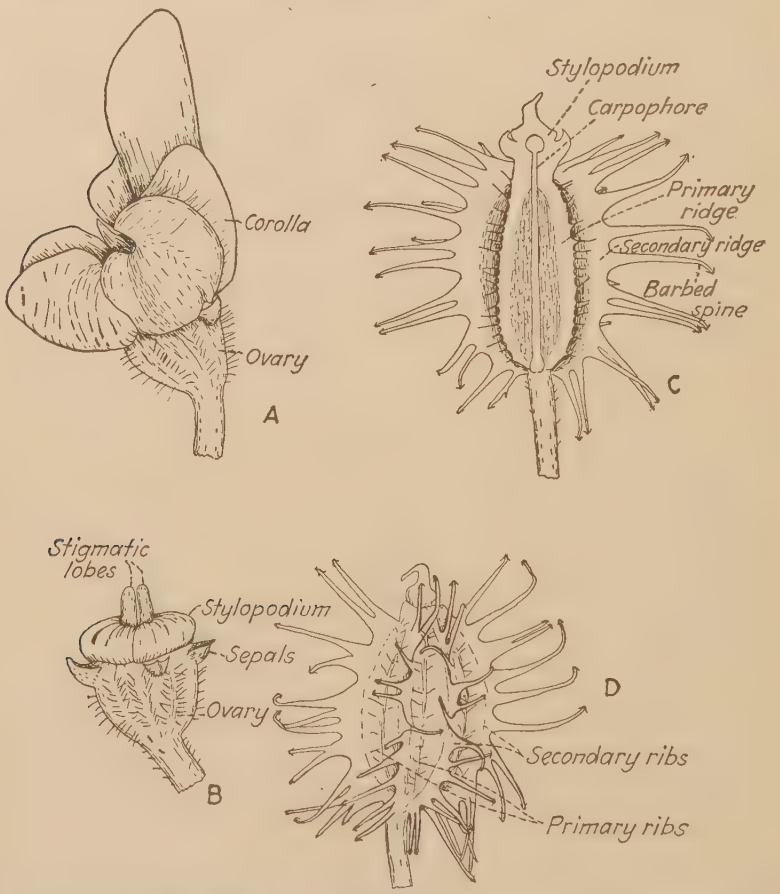

FIG. 37.—Carrot. A. Flower from outside of umbellet. B Petals and stamens removed to show stylopodium and stigmatic lobes. C. Almost ripe mericarp. Commissural view. D. Dorsal view of mericarp.

calyx teeth are lacking. The outwardly directed petals of the flowers at the circumference of the compound umbel are enlarged. There are five separate petals, obovate, with the tips turned in. There are five stamens, curving inward when young. The ovary is inferior and bilocular; in each loculus is a single ovule, which hangs from the median septum, with its micropyle directed upward and outward. The upper surface of the

carpels is occupied by a swollen, nectar-secreting disc continuing into the style and stigma.

Pollination.—The flowers are mostly insect-pollinated, and the number of visitors is large. Nectar is readily accessible, a fact which probably accounts for the great variety of insect visitors. The umbels are also very conspicuous.

Fruit and Seed.—The fruit is a schizocarp, which splits at maturity in the plane of the septum along the commissure into two partial fruits, or mericarps (Fig. 37). Each mericarp is one-seeded and indehiscent; it remains hanging to the forked ends of the carpophore for a time after splitting and has on the outside five longitudinal primary ribs, modifications of the pericarp which bear long hairs. Between the primary are the secondary ribs, which bear about ten long spines, at the ends of which are three or four hooked hairs. Under each secondary rib is an oil tube, of which there are also two on the commissural side.

Climatic and Soil Requirements

Soil Preferences.—The carrot makes its best development in a deep, fertile, well-drained sandy-loam or peat soil. For an early crop, the lighter soils are preferred, but if a heavy yield is desired, the silty loams and muck soils are best. Carrots will grow well on fairly acid soils.

Temperature Requirements.—While the carrot is a cool-weather crop, it is tolerant of high temperature. In the North, it is grown during the summer; in the intermediate states, during the fall and spring; and in the South, during the fall, winter, and early spring.

Culture

Land which is to be planted to carrots should be in fine physical condition. The seeds are small, and the seedlings are delicate at first.

Germination.—The percentage germination of the seed is usually rather low, ranging from about 65 to 80. Kotowski (1926) sowed Chan-

Table 37.—Germination of Carrot Seed at Different Temperatures (*Kotowski*, 1926)

Temperature °C.	4	8	11	18	25	30
First seedling, days after sowing	0	25	16	8	6	5
Last seedling, days after sowing	0	41	23	17	11	8
Seedlings in per cent of seed sown	0	58	56	60	52	54

tenay carrot seed 2 centimeters deep in quartz sand at temperatures varying from 4 to 30°C. As shown in Table 37, no seedlings appeared above ground when held at 4°C. Seeds held at 4°C. for 50 days, then transferred to 30°C., germinated well, however. There was little difference in the final percentage of germination at the temperatures from 8 to 30°C.

The seed is sown in the field about ½ inch deep at the rate of 2 to 3 pounds to the acre; rows are spaced 12 to 16 inches apart. Thinning is seldom practiced. If grown for bunching, the carrots are pulled when they become sufficiently large, giving room for the remainder to develop. Carrots are seldom transplanted.

Marketing

In the South, carrots are grown mainly for bunching. When the roots have reached a diameter of 1 to 1½ inches at the crown, they are pulled, washed, and bunched. They are sold locally or packed in crates or hampers and shipped in mixed cars. In the North, carrots are sold in bulk as well as in bunches. When sold in bulk, the roots are allowed to become larger than when bunched. At time of harvest, the tops are cut off, and the roots, sacked or packed in other containers. In some regions, carrots are used also as feed for dairy cattle.

The yellow color of carrot roots is due chiefly to carotin ($C_{40}H_{56}$), a fat soluble pigment. Carotin dissolves in the butter fat, giving it a deep-yellow color. According to Miss Howard (1925), carotin occurs in a crystalline, or granular, state and is not contained in the stroma of the plastids. It is laid down as a storage product in the medullary rays. The amount of carotin increases from the top of the root downward. Schertz (1925) found that 50 pounds of fresh carrots produced from 1.68 to 3.46 grams of carotin. Red varieties are especially rich in carotin; white varieties are free of it.

Storage

Carrots are stored at a temperature just above the freezing point. They are very subject to soft rot and therefore should not be allowed to become wet while in storage. Kristofferson (1921) found that those roots most subject to rot in storage were the ones with the highest percentage of invert sugar, as shown in Table 38. In four varieties of carrots, he found the total sugar content to range from 6.45 to 8.13 and the invert, from 2.21 to 4.53 per cent.

The ratio of invert sugar to sucrose no doubt varies within a variety under different storage conditions.

TABLE 38.—PERCENTAGE OF SUGAR AND RELATIVE RESISTANCE TO ROT. PER CENT OF FRESH WEIGHT
(*Kristofferson*, 1921)

Variety	Total sugar per cent	Invert sugar		Number of roots stored	Rotted in storage	
		Per cent	Per cent of total		Number	Per cent
Parisian carrot	6.90	4.53	66.3	100	100	100.0
Guerande	6.45	3.46	53.7	78	66	84.6
Nantes, stock A	6.69	3.13	46.8	21	7	33.3
St. Valery, stock A	6.65	2.83	42.4	52	14	26.9
Nantes, stock B	7.17	2.21	30.8	28	2	7.1
St. Valery, stock B	8.13	2.43	29.9	20	1	5.0

CLASSIFICATION AND VARIETIES

Goff (1887) described 28 varieties of carrots, which he considered distinct. He classified them as follows:

Root distinctly pointed

Root long—length exceeding four times the diameter.

Root white—White Belgian.

Root yellow—Yellow Belgian.

Root orange or red—Long Orange, Saint Valery.

Root purple—Purple.

Root half long—length not exceeding four times the diameter.

Root white—Vosges White.

Root orange or red—Danver's Half Long.

Root blunt at lower end

Root long—length exceeding four times the diameter.

Root orange or red.

Root half long—length exceeding two but not four times the diameter.

Root orange or red—Chantenay, Nantes.

Root very short—length not exceeding twice the diameter.

Root orange or red—French Forcing.

Morse (1924) lists the ten most important varieties of carrots in the order of their popularity in America, as follows: (1) Chantenay, (2) Danvers Half Long, (3) Oxheart, (4) Nantes, (5) Long Orange, (6) Red St. Valery, (7) James Intermediate, (8) Short White, (9) Scarlet Horn, and (10) French Forcing.

Chantenay.—The root is 5½ inches long and 2 to 2½ inches in diameter at the crown, tapering to 1 or 1½ inches at the bottom, where it is very blunt, with a decided rat-tail. The crown is small and slightly sunken. The color is bright orange-scarlet, and the core is rather large and definite.

Danvers Half Long.—The root is from 7 to 7½ inches long to where it begins to taper abruptly. The crown is not depressed; its diameter is from 2 to 2½ inches. The color is the same as in Chantenay. The tops are a little larger than those of Chantenay.

Oxheart.—The root, when fully grown, is 5½ to 6 inches long, 3½ to 4 inches in diameter at the crown region, and 2½ inches in diameter just above the taper at the bottom. The crown is depressed. The color is similar to that of Chantenay.

Nantes.—The root is 6½ to 7 inches long and 1 to 1½ inches in diameter, cylindrical, and very stumpy. The core is small, and the skin, smooth. The tops are small, and the crown is depressed.

Breeding

Carrot improvement is carried on mainly by selection and isolation. While carefully controlled experiments have not been made on the amount of self-sterility or self-fertility in the species, observation of isolated plants seems to indicate that there is a high degree of self-fertility. Besides selecting individuals which are true to variety, an effort is made to select roots which have a relatively thick cortex, as these are the best in quality.

Seed Growing

About 80 to 90 per cent of the carrot seed produced in the United States is grown in the Sacramento and San Joaquin valleys of California. Seed for the steckling, or mother roots, is usually sown in July, in rows about 1 foot apart, and in loose soil, so that the roots will develop normally. The seed beds are well irrigated at first; but later, the water is withheld, so that a firm root will be had for transplanting. Much field rotting results from setting overirrigated stock. The roots are usually sufficiently large for transplanting in late November or December; they are rogued when pulled for transplanting. The tops are removed and all off-type, cracked, and diseased roots are thrown out, and the rest are sacked and hauled to the field where they are to be set. Some growers recommend planting as soon as possible after pulling from the seed bed, while others think that better results are obtained if the roots are allowed to cure 10 to 14 days. Different varieties should be separated by a considerable distance, as they cross-pollinate freely. According to Knuth (1898), the cultivated varieties also cross very readily with the wild species. For this reason, it is necessary to eradicate the latter near the seed fields. Heavy, well-drained soil is best. The roots are set upright in checked rows, so that they can be cultivated both ways. They are spaced 30 to 36 inches apart, depending upon the variety. The fields are usually in bloom in June and ready to be cut in early September.

When the crop ripens prematurely or is harvested too green, a large number of the seeds do not have viable embryos. The pericarp may appear well developed and mature, while the embryo is only partially developed. The entire plant is pulled, and the portion below the lower branches is cut off with specially constructed knives, which are often attached to the sides of the harvest wagon. The seed stems may lie in small piles in the field for 2 or 3 weeks; they are then hauled to large canvas sheets, and the heads are chopped off, then spread out to dry. When dry, the seed is threshed out with large wooden rollers or with threshing machines. After threshing, the coarse stems are screened out

FIG. 38.—Carrot seed field in full bloom. Delta region of California.

and the seed, with other fine debris, is sacked and hauled to the cleaning mills. There it is run through gravity seed cleaners and through rubbing machines, which remove the spines. The average yield of carrot seed per acre is about 600 pounds.

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CHAPTER XIV

APIUM

Celery ranks next to lettuce as a salad crop. It is probably more popular in America than in any other country. Here the inner petioles are blanched and eaten as a salad, while in Italy and the Levant the green blades and petioles are used in soups. Celery is grown in almost every state, but it is shipped in largest amounts from New York, California, and Florida. There has been a steady increase in production during the last 10 years. It is grown both as a market-garden and truck crop.

History.—According to Sturtevant, the native habitat of celery extends from Sweden southward to Algeria, Egypt, and Abyssinia and in Asia to the Caucasus, Baluchistan, and the mountains of India. It has been found also in Tierra del Fuego, California, and New Zealand. There is no clear evidence that celery was grown by the ancients as a food plant; if cultivated at all, its use was probably medicinal. The original kind probably had hollow petioles, and even as late as 1821 this was claimed to be the best. At present, however, only those types with solid petioles are grown. Occasionally, within our commercial varieties, plants with hollow petioles appear.

Plant Characteristics

Roots.—Celery develops a great mass of roots within a comparatively small radius. Thompson (1920) found a large part of the root system in the upper 6 inches of soil, with many roots within 2 or 3 inches of the surface, while a few reached a depth of 24 to 27 inches. Most of them are within a radius of 6 inches of the plant. The tap-root is destroyed at time of transplanting, but lateral roots grow out in all directions, and these are covered with fine roots throughout their length. Hundreds of small, fibrous roots 6 to 12 inches long grow out from the base of the plant. Where plants grow to maturity without transplanting, as in the El Monte section of California, a pronounced tap-root is developed.

Stem and Leaves.—During the first year, a short stem develops; while during the second, stems grow 2 or 3 feet high. The latter are much branched and glabrous. The rosette leaves are pinnately compound and have an elongated petiole, which is blanched for food. The petioles are strongly ribbed and expanded at the base. There are usually 2 or 3 pairs of leaflets with one terminal. The foliage varies in color from yellowish green to dark green. The latter kinds are more difficult

to blanch and are known as winter varieties, while the former are called "easy" or "self-blanching." According to Sayre (1924), the outer wall of the epidermal layer of the petiole is cutinized. Collenchyma tissue occurs as separate strands in the apex of the ribs and also as a continuous layer about two cells deep, next to the epidermis. The collenchyma cells are thick-walled, especially in the angles. In longitudinal sections, they are long, pointed, and interlaced, thus giving resistance to bending stresses. Large, thin-walled parenchyma cells constitute the greater bulk of the petiole. Pithiness is probably due to the breaking down of a large area of these cells, leaving open spaces through the center of the petiole. There is a line of large vascular bundles about ⅓ the distance in from the dorsal side of the petiole and also a secondary line of smaller bundles parallel to and about ¼ the distance in from the ventral side.

Flower and Fruit.—The small white flowers are borne in compound umbels among the leaves. The involucre and involucels are small or absent. The flowers are mostly insect-pollinated but are potentially self-fertile. The fruit is an oval, laterally flattened schizocarp with corky ribs and is very small.

Climatic and Soil Requirements

Celery does best on peat, muck, and fertile-loam soils, which are rich in organic matter. These soils are usually fertile, have a high water-holding capacity, and are easy to work. Most of the celery in New York, California, Ohio, Michigan, and Florida is produced on muck. Celery does not grow well on acid soils but will tolerate a considerable amount of sodium chloride, except when young.

It requires a constant and liberal supply of moisture, but the land must be well drained; it cannot be grown in regions of prolonged drought, if irrigation water is not available. It will tolerate considerable heat when once established, but it is difficult to blanch when the temperature is high. It is of highest quality when matured during the cool season of the year, except where freezing temperatures occur frequently. Celery is grown as a summer crop in the North, as a winter crop in the South, and as a spring and fall crop in the intermediate states. In California, the crop matures during the late fall, winter, and early spring, except in Los Angeles County, where it matures throughout the year.

Culture

Growing Plants.—As a rule, celery seed is sown in beds, and 3 to 4 months later the plants are transplanted to the field. In most California districts and in the South, the plants are grown in outdoor seed beds; in the North, they are started in greenhouses, hot beds, or cold frames. The open seed bed should be on fertile soil, preferably muck or one rich

in organic matter, within easy access of water, and protected from winds. In central California, the plants are grown on raised beds 3 to 6 feet wide, which are sub-irrigated by running the water in furrows between the beds. It is especially important that the surface of the beds be well pulverized before seed is sown. Occasionally, the seed is drilled in rows on top of the beds, but usually, it is sown broadcast with special seeders and then covered by raking not over ½ inch deep. If the surface can be kept moist, the seed is just barely covered. The seed bed is often given a light rolling after seeding to pack the top soil and break the small clods.

When started indoors, a good range of temperature for germination is from 15 to 20°C. Some growers sprout the seed before sowing. Several

FIG. 39.—Growing celery plants for transplanting. Delta region of California.

days before planting, an ounce of seed is mixed with a quart of finely sifted moist muck; when the seed has swelled or the radicle just begins to show, the seed is planted. A cloth covering may be placed over the bed until the seedlings appear. They are sometimes transplanted once before they are set in the field.

When plants are started in hot weather, soil must be used which is cool and retentive of moisture. After seeding, burlap or similar material is spread over the surface; straw may be used, also. When seedlings are through the soil, the covering is partially or entirely removed, to admit light. Cheesecloth may be used as a cover until the seedlings have become well established. The shade should be entirely removed several weeks before transplanting, to harden the plants.

Transplanting.—Celery plants should be ¼ to ⅜ inch in diameter at the crown when ready to transplant. Only the sturdy plants are set.

The general practice is to trim both roots and tops before resetting; trimming the roots makes planting easier and causes the growth of a fibrous-root system. Until transplanted, the trimmed plants are usually carried in pans filled with water but only partially so that the crowns are not submerged. Transplanting is done entirely by hand. Plants may be set on the level, in the bottom of shallow furrows, or on the sides of furrows, depending chiefly upon the method of irrigation. They may be set in double rows, but the single-row system is in vogue where the blanching is done with soil. They are set usually 6 to 8 inches apart in the row, but the distance between rows depends mainly upon the method of blanching to be used. When the crop is to be blanched with soil, the rows are spaced 4 to 6 feet apart; when boards or other material are used, the rows may be closer.

Premature Development of Seed Stem.—Occasionally a considerable proportion of the plants form flower stems prematurely. Such plants are a total loss. In an effort to determine the reason for premature seeding, Thompson (1923), in New York, with the Golden Self Blanching variety, tested the effect of the following treatments: (1) changing planting date, (2) checking growth by withholding water before transplanting or by crowding in the flats, and (3) exposure of plants to freezing temperatures and to temperatures just above freezing. Date of planting was the only factor that markedly influenced the per cent of plants going to seed. Seed sown Dec. 10, Jan. 10, Feb. 10, and Feb. 25 developed 86, 58, 21, and 4 per cent seed stems, respectively. Checking growth by drying or crowding or subjecting to low or freezing temperatures exercised little influence.

Cultivation.—After the plants have become established, the rows are worked with a special machine which straddles them and scrapes the soil and weeds away. The blades are run shallow and as near the plants as possible, to reduce the amount of hand labor. A narrow strip of weeds and untilled soil is left in the row, which must be cultivated by hand. All cultivation should be shallow.

Blanching.—Blanching consists of destroying or preventing the development of chlorophyll by keeping the light from the inner leaves or by other means. It can be done by soil, boards, paper, storage in dark cellars, or ethylene gas. Soil is used almost exclusively for blanching the late or main crop, where there is considerable frost hazard. As the crop approaches maturity, or 2 to 3 weeks before shipment, a bank of soil is gradually raised against each side of the row, until it is 12 to 15 inches high. Several operations are usually required. Blanching with boards or paper is usually practiced with summer celery or celery which matures in a very mild climate during fall, winter, or spring. One-inch boards 16 feet long and 12 inches wide are generally used. These are laid on edge on both sides of the celery row and are held together at the top by cleats or wire

hooks. It requires from 10 to 20 days for a well-blanched heart to develop. Heavy paper 12 inches wide is also used for blanching early celery. The rolls are generally placed on reels and unrolled on each side of the row. The paper is held in place by a heavy wire arch placed every few feet. A good grade of paper may be used two or three times. Newspapers are employed to some extent; they are wrapped about each individual plant or are otherwise specially prepared. Their use, however, is no longer popular, on account of the extra hand labor which it involves.

In general, celery is either partially or entirely blanched before it is harvested. Harvey (1925), however, showed that celery can be blanched with ethylene gas after harvesting. He states that after blanching, the petioles are as brittle and sweet as soil-blanched celery, even the old leaves being free from the characteristic bitter, acrid taste, and the keeping quality is good. The green varieties are more vigorous than the self-blanching; they have more chlorophyll to aid in the manufacture of sugar and starch, but their bitter, acrid flavor and the difficulty with which they blanch has made their use rather restricted; when blanched with ethylene, however, they are of a better texture and flavor than are the self-blanching types. The activity of the starch-digesting enzymes seems to be increased by the ethylene treatment, and the fibrous materials of the petiole seem also to undergo partial digestion, making them more brittle. Harvey is of the opinion that the green varieties will be grown to a greater extent when the practice of blanching with ethylene becomes general. If the haul is a long one, the celery can be wholly or partially blanched during transit, or if the haul is not too short, blanching can be started before loading and completed during transit. If the celery is intended for storage, blanching should not be complete prior to storage.

A tight room or container must be used for the ethylene treatment. The celery should be set loosely in an upright position, and the atmosphere kept moist to prevent wilting. Temperature should not go above 27°C. The self-blanching varieties can be blanched in about 6 days at 18°C. at a concentration of ethylene in air ranging from 1:1,000 to 1:10,000. The concentration of ethylene should not be higher than 1 part in 1,000 parts of air. For the green varieties, 10 to 12 days are required for blanching. If the rooms are not tight, a second dose of ethylene is given after 6 days. It is necessary to leave more space in the room than that actually occupied by the celery, because the rate of respiration is increased by ethylene treatment; therefore, considerable O_2 is needed. Mack (1927) states that the rate of respiration is doubled when celery is treated with ethylene at the rate of 1 part to 50,000 parts of air. He found that "in the presence of very high concentrations of carbon dioxide, ethylene at the rate of 1:10,000 failed to produce any blanching at all." The ethylene gas is bought in steel tanks under pressure. When liberated into the chamber, the amount may be measured by use of a gas meter.

Harvesting.—At harvest time, plants which have been blanched with boards or paper are usually cut off just below the crown with a sharp spade or other implement. Celery blanched with earth is generally loosened by means of a horse-drawn cutter with a blade running just below the crown. The trimmers then lift the celery and remove the outer leaves and excess roots.

Marketing

Grading.—The grade specifications for "rough" celery, as outlined by the Bureau of Agricultural Economics, are as follows:

U. S. Grade No. 1 shall consist of well trimmed stalks of celery of similar varietal characteristics which are not pithy or wilted and which are free from damage caused by seed stems, freezing, disease, insects or mechanical or other means.

In order to allow for variations incident to proper grading and handling, not more than 10 per cent, by count, of the stalks in any lot may be below the requirements of this grade but not to exceed one-fifth of this tolerance or 2 per cent shall be allowed for decay.

U. S. Grade No. 2 shall consist of stalks of celery which do not meet the requirements of U. S. Grade No. 1.

In California, celery which is to be shipped long distances in refrigerator cars or held in storage is packed in the crates in the field; but in Florida, a large proportion of the celery is washed before shipment. When preparing for market, the outer leaves are trimmed off and the remaining portion washed. If the delivery is directly from field to local market, final preparation is given at the farm. In all of the large markets, however, some dealers are equipped to trim, wash, and bunch the celery before it is offered for sale. The standard bunch contains about a dozen plants, the exact number depending upon their size.

Shipping Seasons and Carlot Movements.—The most important shipping states are California, Florida, New York, Michigan, and Oregon. Celery moves from California throughout the year; from the Delta region from October to January, from central California from November to January, and from southern California from November to July. The Florida crop moves from January to June, with the peak in March or April; the Michigan crop from June to January, with the peak in October; the New York crop from July to January, with the peak in October, November, or December; and the Oregon crop from August to November, with the peak in October. The months of lightest shipment are June and July and of heaviest shipment, from October to April. From 1921 to 1926, there was an increase of approximately 50 per cent in carlot shipments of celery for the United States.

TABLE 39.—CARLOT SHIPMENTS OF CELERY BY MONTHS FOR UNITED STATES, 1921–1926

Year	January	February	March	April	May	June	July	August	September	October	November	December
1921	1,675	1,746	1,754	866	255	105	137	262	516	1,815	1,443	1,909
1922	1,423	1,392	1,749	1,204	466	93	201	369	829	2,107	2,040	2,278
1923	1,999	1,894	2,510	1,681	393	87	219	364	617	2,084	2,392	2,669
1924	2,848	2,146	2,474	1,467	655	123	257	431	817	2,187	2,476	2,710
1925	2,378	2,170	2,486	2,024	1,228	323	456	654	1,335	2,471	2,847	2,736
1926[1]	2,294	1,501	1,989	2,189	622	421	394	539	1,060	2,384	2,540	3,255

[1] Subject to revision.

TABLE 40.—SHIPPING SEASONS AND YEARLY CARLOT SHIPMENTS BY STATES, 1921–1926

State	Shipping season	1921	1922	1923	1924	1925	1926[1]
California	October to July	3,405	3,474	4,527	4,519	5,339	5,934
Colorado	August to November	211	222	125	197	399	173
Florida	January to June	4,172	4,955	6,412	7,205	7,951	5,394
Idaho	October to November	11	26	49	48	29	13
Michigan	June to January	1,013	1,612	1,485	1,311	2,226	1,825
New Jersey	June to November	216	119	216	180	149	132
New York	June to April	3,110	3,347	3,585	4,445	4,305	4,951
Ohio	August to November	65	76	55	64	71	44
Oregon	August to November	43	82	205	363	398	445
Pennsylvania	August to November	225	212	223	225	208	193
Utah	October to November	.....	6	2	7	20	19
Washington	October to December	7	16	17	15	3	5
Total for United States		12,483	14,151	16,909	18,591	21,108	19,188

[1] Subject to revision.

STORAGE

Celery may be stored in trenches, pits, field storage houses, or cold-storage warehouses. Storing in trenches is practiced where a surplus is to be held for a short time only. The trenches are 12 to 18 inches wide and usually shallow, and the plants are packed closely in it and covered to prevent freezing. The pit is temporary, while the field storage house is a permanent structure; both are constructed partially underground. The methods of storage in each are similar, and each is used in the North chiefly to hold celery until the holiday seasons. The main essentials are to keep the temperature low, the roots moist, and the tops dry and to

provide good ventilation. Holding celery in cold storage is done mainly at the terminal shipping points and has become the most popular method. In cold storage the temperature can be held at about 0°C., which is the best storage temperature. Thompson (1917) found that celery kept better in small crates than in large ones; this was probably because the temperature could be kept lower and better aeration given in the smaller crates.

As the storage period advanced, Corbett and Thompson (1925) found that there was an increase in the soluble pectic compounds (pectic acid, pectin) and a decrease in the more insoluble. The variety Golden Self Blanching was used. Both reducing and total sugars in the leaf-blades showed a marked decline from the time of harvest (Oct. 22) to the end of the storage period (Dec. 6). This decrease was due probably to translocation of the sugars to the petioles. In both outer and inner petioles, the total and reducing sugars increased until toward the end of the storage period, when there was a sharp decline. Soluble N increased in both leaf-blades and petioles from harvest time until toward the end of the storage period, when there was a very marked decrease in the former and a slight decrease in the latter. Insoluble N was high in the leaf-blades at harvest time and, in general, decreased from that time to the end of storage. In the outer petioles, the insoluble N decreased during the first month, and for the next few weeks there was little change, followed by a sharp decline. Insoluble N increased in the inner petioles from harvest time until toward the end of storage, after which there was a decrease. Probably the increase in insoluble N in the inner petioles was a result of translocation from the outer leaves and blades of the inner leaves. During storage, there is usually some growth of the heart leaves, and this probably takes place partially at the expense of the carbohydrate and protein compounds stored in the outer leaves.

Varieties

Work (1925) has listed as standard varieties Golden Self Blanching (Old and New Vilmorin and Golden Plume strains), Easy Blanching, and Giant Pascal. As secondary varieties, he names White Plume, Columbia, Emperor, Schumacher, Boston Market, French Success, Winter King, and Winter Queen.

Golden Self Blanching.—This is the most important of all celery varieties representing well over ½ the total crop. It probably originated as a sport from a green winter variety. Green rogues appear occasionally. The plant is either tall or short, depending upon the strain or type, erect, compact in growth, and medium early. The foliage is of a yellowish-green color; the petiole is thin, sharp-edged, and deeply ribbed. The heart is large, grows up vigorously after blanching has started, and, when blanched, is a light golden-yellow color.

Easy Blanching.—This variety is of rather recent introduction. In comparison with Golden Self Blanching, it is somewhat shorter, less erect, more vigorous, has darker foliage, and is a better keeper. It blanches a little more slowly than Golden Self Blanching.

Giant Pascal.—This variety is the leading late, or winter, variety. It is medium in height, erect, and compact in growth. The foliage is dark green in color; the petiole is thick and round edged; the ribs are broad and shallow. It blanches slowly to a creamy-white color. The quality is very good. The heart is rather small compared to the size of the entire plant. This variety will probably come into greater prominence when the method of blanching on a commercial scale with ethylene is perfected.

Seed Growing

Knuth (1898) notes that the flowers of celery are self-fertile. It is possible to obtain a good set of seed under conditions of isolation.

Much of the seed used in the United States is imported from France; some, however, is grown in California and in the North. In France the seed plants are started late in the season and allowed to grow rather thickly in rows about 3 feet apart. During the fall, they are rogued; during the winter, the plants are covered lightly with straw or given some other protection; in the spring, seed stems develop, blossom, and produce seed.

In California, seed plants are started during the summer and transplanted during the late fall or winter. The plants are only partly grown, but they are rogued at time of setting, for habit of growth and color. They are rogued again later. They are set about 3 by 3 feet apart. If mature plants are used for seed, the outer leaves are removed and the roots reset in November or December.

Diseases

Bacterial Leafspot (*Bacterium apii*).—This disease occurs very generally in the North and seems to be confined to the leaf-blades. The lesions are of a rusty brown color, irregularly circular in outline, rarely exceed 5 millimeters in diameter, closely resemble those of Septoria, and may be distinguished from them with certainty only by the absence of pycnidia. Occasionally, the lesions are so numerous as to cause the death of many of the older leaves, but usually, the injury consists in disfiguring the foliage and in a possible reduction in growth of the plants. According to Jagger (1921), good control is obtained by spraying with 5:5:50 Bordeaux.

Early Blight (*Cercospora apii*).—This disease is widespread in the United States and causes considerable loss in some areas. Badly infected plants look as if they had been scorched by the sun. Under dry con-

ditions, they appear to wilt more readily than do healthy plants. The older leaves fall and are soon covered with a grayish, velvety mass of fruiting bodies. On the leaf-blade, the disease first appears as yellowish spots 1 millimeter or more in diameter. These enlarge and coalesce to form diseased areas 1 to 2 centimeters in diameter within 10 days after inoculation. The lesions are approximately elliptical in shape and cause a wrinkling or slight folding of the surrounding healthy tissue. They change from a brownish color to a dull slate or ashen gray, as the fruiting bodies appear. The petioles are attacked occasionally, the lesions on them appear water-soaked and are elongated.

According to Klotz (1923), the fungus enters the host through the stomata by means of conidial germ tubes. It grows intercellularly, absorbing nutriment from the surrounding tissue by means of haustoria. The conidiophores project through the stomata and produce conidial spores, which are distributed by wind and are the chief means of infection. The fungus overwinters on celery refuse in stroma-like masses of heavy-walled, mycelial threads. For the control of this disease, Foster and Weber (1924), in Florida, recommend spraying with 4:4:50 Bordeaux. The spray should be first applied in the seed bed as soon as the young leaves begin to develop. In seed bed and field, the spray should be applied every week or 10 days. Bordeaux at this strength gives best results when applied at the rate of about 100 gallons to the acre. For the control of early blight, Klotz (1923) recommends, in addition to spraying, growing the crop on a moist, fertile soil and destroying all refuse. Crop rotation, no doubt, will also help to keep this disease under control.

Late Blight. (*Septoria petroselini* var. *apii*).—This disease is usually found wherever celery is grown. It is generally considered a cool-weather disease. It attacks all parts of the plant aboveground but is found principally on the leaf-blades, where it produces small, circular lesions. These are at first slightly darker than the surrounding tissue, but later, they become almost black, due to the pycnidia, which may reach the margin of the infected area. The pycnidia, or fruiting bodies, of the fungus develop immediately underneath the epidermis and produce the long, cylindrical spores by which the disease is propagated. It is these spores also, which carry the disease over winter. They are able to leave the pycnidium only when moisture conditions are favorable; this fact accounts for the rapid spread of blight during periods of foggy and rainy weather. The spores are disseminated by water, wind, insects, machinery, and other means. Planting disease-free seed and spraying with Bordeaux are the control methods generally recommended. The spores are usually dead on 2-year-old seed. If new seed is used, it is necessary to treat it in hot water or corrosive sublimate. In the hot-water treatment, a cheesecloth bag half filled with seed is immersed in water and held at exactly 48°C. for 30 minutes. When the corrosive sublimate treatment is used, the

seed is soaked in warm water for 30 minutes, drained, then immersed in a 1:1,000 corrosive-sublimate solution for 30 minutes, then rinsed and dried. Warm water softens the seed coats and causes the spores to exude from the pycnidia. The latter are then killed by the poison. If there is danger of the disease's appearing in the field, Bordeaux (5:5:50 formula) should be applied early. Usually, several applications of spray are given in the seed bed. As previously stated, this spray will likewise keep bacterial leafspot and early blight under control. In the field, it is usually necessary to spray every week or 10 days, if dews and rains are prevalent. A system of crop rotation will also help to keep late blight under control. Late blight continues to develop in transit; so at time of packing, it is necessary to remove all diseased leaves.

Blackheart.—Blackheart is a non-parasitic disease, which does considerable damage in some seasons and is present in most celery districts. The center, or heart leaves are blackened, and the tips of the older leaves often turn brownish black and shrivel up. Gradually, all of the heart leaves are involved. The disease is conspicuous only when the plants are cut open. Foster and Weber (1924) state that the most important factor associated with its production is unbalanced water relations; but any check to the growth of the plant and high temperature also increase the amount of injury. The mature plant is more subject to injury than the immature one. The most effective means of control is to provide the best conditions possible for the growth of celery. The soil should be kept moist but not water-logged; good drainage is necessary. The crop should not be allowed to become stunted and should be cut as soon as it is mature; it should not mature during hot weather.

Pithiness.—At times, considerable loss is had by the outer petioles' becoming pithy. In many cases, most of the petioles of the plant are hollow. The work of Austin and White (1904) with Golden Self Blanching seems to show that pithiness is hereditary and can be eliminated by selection. Foster and Weber (1924), in Florida, state that its appearance may also be associated with unfavorable growing conditions or any other condition which checks the growth of the plant. Plantings from the same lot of seed produced different amounts of pithiness when grown under different conditions.

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CHAPTER XV

PETROSELINUM

Parsley is native to the Old World. According to Sturtevant, it formed part of the festive garlands of the ancient Greeks and Romans, and during the time of Pliny, there was not a salad or sauce served without it. At present, parsley is cultivated everywhere in small amounts and is used for seasoning in soups and as a garnish. The plant is a biennial, forming a thickened tap-root and a rosette of leaves the first year; the

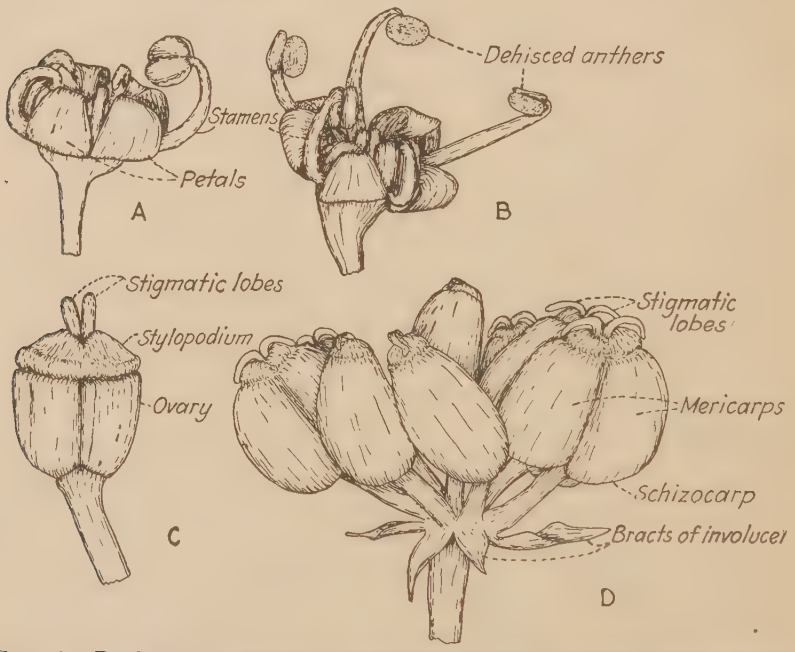

FIG. 40.—Parsley. A. Stamens just starting to unfold. B. Flower with three anthers dehisced. C. Just after anthesis, showing the stigmatic lobes, stylopodium and developing ovary. D. Involucel of nearly mature schizocarps.

second year, the stem elongates, branches, and produces compound umbels. The flowers are small and greenish yellow; they are self-fertile. The fruit is about $\frac{1}{8}$ inch long and conspicuously ribbed.

In the North, the plants are usually started indoors. The seed is slow to germinate, and the seedlings are delicate and need some protection at first. They are later transplanted to the field about 12 inches apart in rows 2 feet apart. In the South, parsley is grown as a fall,

winter, and early-spring crop. In the Norfolk, Virginia, region, it is grown in considerable quantity in cold frames during the winter. There, in August, parsley is planted in rows 12 inches apart with radish, or rape, which serves as a nurse crop, being removed when the parsley seedlings appear.

In harvesting, a few of the outer leaves are removed; new leaves continue to develop throughout the season from the crown. For shipment, the leaves are bunched or packed loose in hampers, crates, or lug boxes, with cracked ice.

Varieties

Sturtevant describes five forms of parsley: (1) common, or plain leaved, (2) celery leaved, or Neapolitan, (3) curled, (4) fern leaved, and (5) Hamburg, or turnip rooted. The plain-leaved parsley is now being superceded by the more ornamental curled forms. Leaves of the latter are flat and deeply cut. It is used mainly for flavoring. The celery-leaved form, according to Sturtevant, is scarcely known outside of Italy. Its leaf-blades and petioles may be blanched like celery. Of the curled parsley, there are many varieties, which differ mainly in the degree of curling and the fineness of division of the leaf segments. The fern-leaved parsley has leaves which are not curled but are divided into a large number of small segments very dark green in color. Hamburg, or turnip-rooted parsley, is grown for the root, which is similar in color and shape to the parsnip. It is used in the same way as parsnips are and may be stored for winter use. The leaves are plain and may be used for flavoring.

Seed Growing

The production of parsley seed is largely localized in the Santa Clara Valley of California. Seed is planted in May or June at the rate of 4 to 6 pounds per acre on raised beds similar to those used for the growing of lettuce. One acre of seed bed will plant about 40 acres for seed. The roots are dug in December, sorted, and transplanted 32 to 36 inches apart. The seed matures slowly; it is ordinarily not ready to harvest until September. The crop is usually harvested by stripping the plant of the seed-bearing branches. The entire crop is usually harvested at one time. It is then dried, rolled, screened, and milled. The average yield of seed is about 800 pounds per acre. The plain-leaved varieties are the heaviest seeders.

CHAPTER XVI

PASTINACA

The cultivated parsnip is grown to a very limited extent in the United States. In the North, it is produced chiefly as a market-garden crop.

History.—According to Sturtevant, the parsnip has been grown from an early period; it was probably cultivated by the Greeks and Romans. The wild plant is native to Europe and has become naturalized in North America. The tap-root of the wild plant is spindle shaped, white, aromatic, mucilaginous, and sweet. In 1683, long parsnips were used in England as a delicacy. The parsnip was brought to America by the early colonists. It is mentioned as cultivated in Virginia in 1609 and as common in Massachusetts in 1629.

Plant Characteristics

The parsnip is a biennial. During the first year, food is stored in the fleshy, edible "root." The plant develops slowly, taking the entire growing season to reach its maximum size.

Roots, Stems, and Leaves.—The so-called "fleshy root" develops from the primary root, the hypocotyl, and the plumule; that portion giving off lateral roots is the tap-root. The short, compressed crown, with its rosette of leaves, arises from the plumule; the region below, without lateral roots, arises from the hypocotyl. During the second spring, a branched, grooved stem develops 3 to 5 feet high, becoming hollow. The lower leaves are petiolate, becoming sessile above. They are pinnately compound, and the terminal leaflet is usually three-lobed.

Inflorescence and Flowers.—The flowers are in broad, compound umbels, without involucres or involucels. According to Beghtel (1925), the individual flowers arise as club-shaped masses of meristematic cells from the broad surface of the developing axis of the umbel. The primordia of the petals, stamens, and carpels appear in the order named. The two carpels unite along their inner margins to form an arch over a single ovarian cavity. Before the carpels unite, the inner edges are sharply incurved, so that the union is accomplished by the outer surface some distance from the edge. Thus, the cavity of the ovary contains the edges of the carpels, which continue to grow and finally divide the cavity into two locules, each containing two reflexed edges of a carpel. From each of these edges, an ovule begins to develop; but soon, one degenerates in each locule. The mature ovule is completely anatropous.

The flower is yellowish green and epigynous. The sepals are rudimentary. The ovary is compressed laterally and bears two free styles, which unite at their base to form the large nectary, or stylar foot. According to Beghtel (1925):

> . . . this stylar foot develops early, and by the time the anthers begin to mature it secretes a nectariferous fluid. At this time the styles are very short and have not yet developed stigmatic surfaces. It is about 5 days after the first stamens of a flower begin to dehisce that the stigmas of the same flower are ready to receive pollen. The flowers of the outermost whorl in an umbel mature first. These are followed by those of the next whorl within, which shed their pollen at the time that the stigmas of the flowers of the outer whorl are receptive.

Pollination within the umbel seems to be the rule; that between umbels is not common. The last whorl of flowers at the center of the umbel usually fails to set seed, because of the failure to be pollinated.

Fruit and Seed.—The fruit is a schizocarp, which splits at maturity into two mericarps commonly known as the "seed." The two lateral ribs of the mericarp are expanded into broad, flat wings; the dorsal and two intermediate primary ribs are rudimentary. The oil tubes are solitary in the grooves, and there are two to four on the commissural side. The seed remains viable for 1 to 2 years only.

Climatic and Soil Requirements

The parsnip requires a long growing season for its development; when the summers are hot, it makes its best growth during the cool days of spring and fall. The best soil is a deep sandy loam; in a heavy soil, the roots become much branched, and this is undesirable.

Culture

Seed is planted in early spring about ½ inch deep in rows 15 to 18 inches apart at the rate of 4 to 6 pounds per acre. As it germinates very slowly, land comparatively free from weeds should be used. Radish seed is sometimes sown with the parsnip, to mark the rows and permit early cultivation. When 1½ to 2 inches high, the plants may be thinned to about 4 inches apart in the row. Young plants are rather feeble but are fairly hardy after they have become established. In the North, the crop is usually harvested in late fall and then stored. The roots are not injured by freezing and may be left in the field over winter, even in the North. This practice is unsatisfactory, as digging is often delayed because of wet weather in early spring. The roots are generally turned out with a plow.

Marketing

Occasionally, the harvested young plants are sold in bunches of about six. Most of the crop, however, is allowed to grow to maturity; the roots are topped and then marketed from the field or storage in sacks.

Storage

In the North, parsnips are stored in outdoor pits, or vegetable cellars, so that they may be removed and marketed during the winter. When left in the field over winter, they improve in texture and edible quality. It has generally been thought that the changes which took place were due to freezing. Boswell (1923), however, has shown that the same changes occur, only more rapidly, when the roots are held just above 0°C.

Table 41.—Composition of Roots Left in Soil over Winter and When Stored at about 1°C. in Air
(*Boswell*, 1923)

Harvested	Moisture		Free-reducing sugars		Sucrose		Starch		Polysaccharides	
	Soil	1°C.	Soil	1°C.	Soil	1°C.	Soil	1°C.	Soil	1°C.
	Per cent	Per cent	Per cent of dry weight							
Oct. 31	75.9	75.9	0.9	...	16.3	....	32.6	....	46.7	
Nov. 8	74 6	74.3	0.8	1.4	20.3	40.2	31.3	11.8	39.9	19.8
Nov. 23	75.6	76.8	1.0	1.9	27.9	46.5	26.2	2.9	35.2	13.2
Dec. 7	76.4	74.4	1.0	1.5	33.1	49.9	17.7	1.2	26.2	11.4
Jan. 6	78.9	73.5	1.0	1.5	43.7	51.5	6.3	1.3	15.7	10.4
Feb. 1	79.8	74.3	1.3	1.9	45.4	52.4	4.2	0.0	12.8	9.6
Mar. 14	79.7	74.4	2.2	2.3	46.5	53.2	3.4	0.0	....	9.2

As shown in Table 41, there was a slight increase in moisture content of parsnips left in the soil, while those in storage remained nearly constant in this respect. The free-reducing sugars increased slightly in amount. The most pronounced changes were the increase in sucrose and the decrease in starch. Changes occurring in roots in the field were slower than those occurring in roots in storage, probably because of the higher temperatures prevailing for a time under field conditions. When roots were taken from storage at 1°C. and placed at a higher temperature, starch again appeared showing that the reaction is reversible. The increase in edible quality is due chiefly to the accumulation of sucrose and the decrease in starch.

Varieties and Seed Growing

Hollow Crown, so called for its depressed crown, is the variety most generally grown.

Most of the parsnip seed used in the United States is grown in California. Seed is drilled in a well-prepared seed bed in August at the rate of 8 to 10 pounds per acre in rows 12 inches apart. Thinning is usually not necessary. For transplanting, the plants are topped about 3 inches aboveground, then plowed out, selected, and sacked. It has been found best to let the roots cure for about a week in the bags before setting in the seed fields. Fields which are to receive the roots should be plowed deeply. After the field has been well prepared, the roots are set 3 by 3 feet apart by use of a dibber or special hoe. The crown of the parsnip should be set flush with the soil surface. Under good growing conditions the flowering stems reach a height of 6 feet. When the seed is ripe, the seed stems are cut from the central axis and placed on canvas drying sheets. After drying for a week or 10 days, the seed is rolled and then given a last screening. The final cleaning is given in the seed mills.

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PART IX

CONVOLVULACEAE

As the name indicates, the members of this family are mostly climbing twiners. Most of the forty or fifty genera of Convolvulaceae are natives to the tropics, though several are now found growing wild in southern United States. The sweet potato is the only member of the family important as a crop plant. Several others are very persistent weeds in cultivated soils.

CHAPTER XVII

IPOMOEA

The sweet potato is an important food crop in all tropical as well as sub-tropical countries. In the South, it has been grown since colonial times. During the last few decades, it has become better known as a food in the North, resulting in a great increase in its commercial production and in shipments. The recent development of methods for storing sweet potatoes on a large scale has also favored increased consumption. The northern limits of sweet-potato production are reached in central New Jersey on the Atlantic coast, central Iowa in the Middle West, and the Yakima Valley of Washington on the Pacific coast.

Taxonomy.—The sweet potato (*Ipomoea batatas*) belongs to the *Convolvulaceae*, or morning glory, family. There are over 400 species of *Ipomoea*, sweet potato being the only one which produces edible roots; other species, however, have roots of medicinal value. The specific name for sweet potatoes, *batatas*, was applied by Lamarck in about 1800, that being the Indian name which had been in use for centuries. This vegetable was the first one called "potato"; the Irish potato was so called later because of its supposed resemblance.

Another family, the *Dioscoreaceae*, has several species with trailing stems and enlarged underground tubers, some of which are edible and known as "yams." The term is improperly applied to the moist-fleshed varieties of sweet potatoes in the United States.

History.—Sweet potatoes are generally considered to be native to the American tropics. Peter Martyr described nine varieties cultivated in Honduras in 1514. The Spaniards and Portugese distributed them throughout the tropics. They were grown in Virginia before 1650. Burr lists nine varieties grown there in 1863. Many varieties distinct from those now known in America exist in Hawaii, China, and other warm countries. They were introduced into China between 1573 and 1626. American varieties have come chiefly from the West Indies. Undoubtedly some new forms have arisen during the 300 years they have grown in this country.

Plant Characteristics

Stem.—The central axis terminates just above the surface of the soil, giving rise to several prostrate lateral branches. These laterals are not much branched; they range in length from 2 feet in the so-called "vine-

less" varieties to over 20 feet in some of the "viny" sorts. The number of nodes per stem is about equal in the two types, but in the vineless varieties, the internodes are very short. The stems vary from $\frac{1}{8}$ to $\frac{1}{4}$ inch in diameter; in some varieties, they are inclined to twine. Fasciation is common in sweet potato stems. The color varies from green to brown in different varieties. Lenticels are abundant, and young stems are pubescent, but the hairs generally do not persist in older stems. Both cortex and pith of the stems are traversed by numerous latex canals containing a milky juice, which becomes black and sticky upon exposure to air. Neither the composition nor the function of the latex fluid is known; some writers think it is a waste product of the plant's metabolism. Kniep (1905) showed that the latex was not reserve food and that it took little or no part in the translocation of nutrients.

Leaves.—The long petioles always assume an erect position. Just below the leaf-blade are two small papillae, one on each side of the petiole, containing the petiolar nectaries. The leaves are cordate or hastate and slightly or deeply lobed, in different varieties. Although leaf shape varies considerably on different parts of the same plant, it is constant enough to serve as a taxonomic character in varietal classification. The veins are palmately arranged and prominent on the lower surface; they may be heavily pigmented, usually the same color as the stems. Hairs occur on the upper surface of the leaf, consisting of several epidermal cells supporting two or three short and one long pointed terminal cell, with thickened walls. The anatomy of leaves and stems has been described by Groth (1911).

Roots.—Roots arise from opposite sides of each node, or leaf scar, on the underground portion of the stem as well as from the nodes of the aboveground stems, when these rest on moist soil. All of the roots are small and fibrous at first, but most of them become thickened during the growing season. A few become very much thickened for a short distance from the central stem, forming the edible roots. Turpin (1830) first showed that the thickened underground parts are really roots, not thickened stems or tubers. Some botanists have questioned this conclusion, but Artschwager (1924) says "the exarch position of the protoxylem decides, without further argument, in favor of the root structure theory."

Miss McCormick (1916) and Artschwager (1924) described the anatomy of the roots. The mature thickened root varies from the young root chiefly in the distortion which accompanies the greatly increased amount of thickening. In the young root, there is a thick cortex, separated from the vascular tissue by an endodermis and the pericycle. The xylem and phloem are arranged radially in alternating strands. The cambium is organized very early and forms an irregular cylinder separating the xylem and phloem elements. As the root enlarges, cells are formed by the cambium more rapidly between the points of the xylem,

gradually making the cambium cylinder more symmetrical. Where the lateral roots form, there are breaks directly opposite the points of the primary xylem. These breaks, like greatly widened medullary rays, extend for some distance on each side of the place of attachment of the lateral roots. The lateral roots arise in the pericycle from meristematic cells opposite the primary xylem groups. There may be as many rows of lateral roots as there are groups of primary xylem, a number varying somewhat, but most of the roots are either pentarch or hexarch. Longitudinal rows of lateral-root scars are seen even in the mature root.

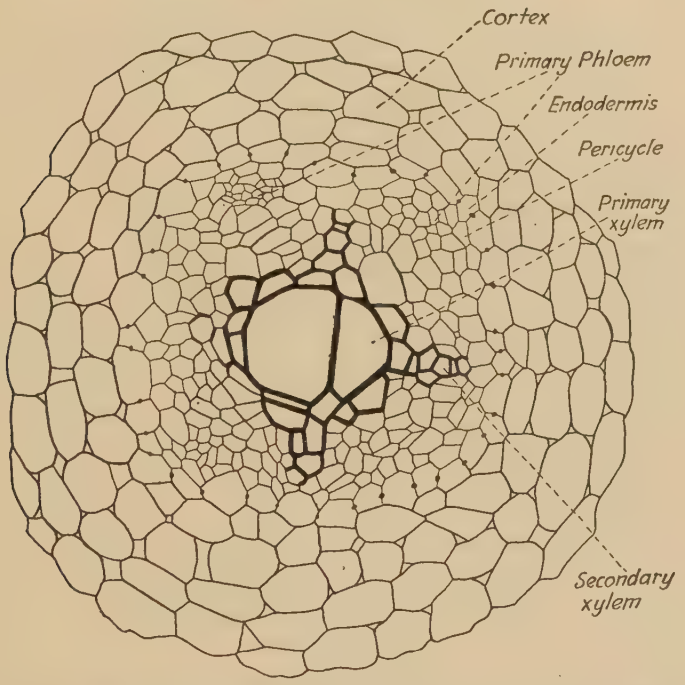

FIG. 41.—Cross section of a young root of sweet potato. (*After Artschwager*, 1924.)

Enlargement of the fleshy root begins a short distance from the point of attachment to the stem, by the rapid divisions in the central parenchyma. This cell division increases in amount, separating the xylem into strands, each strand containing one to several vessels. Around these, secondary cambiums form, which, throughout the growth of the root, produce both xylem and phloem in scattered strands, each of which in turn becomes surrounded by a new cambium. In a cross-section of a thickened root, the xylem is in isolated groups surrounded by actively growing cells. The cells of the cortex increase in number to accommodate the increasing circumference of the root. The cells of the

interstitial parenchyma and of the cambium are gorged with starch grains. Frequently, groups of xylem elements run in strands through the cortex and continue on the surface, forming longitudinal ridges known as "veins." Veins occur when thickening of the root is extraordinarily rapid. The peripheral cells are covered by a root epidermis, which soon becomes torn and disintegrates, being replaced by a periderm, which increases in thickness after the roots are taken from the soil. The mature

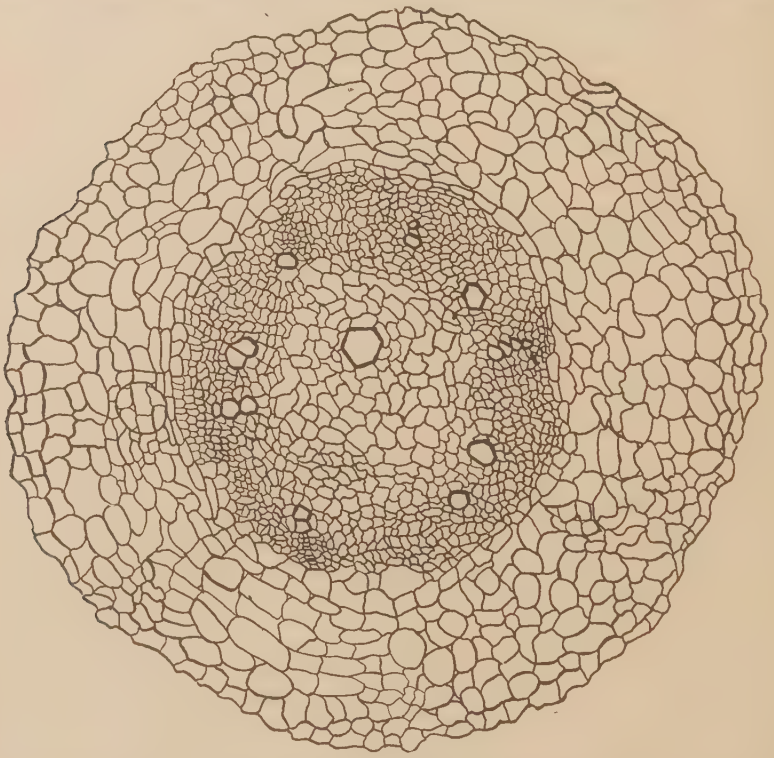

FIG. 42.—Cross section of sweet potato root 4 mm. in diameter. The secondary xylem and the secondary cambium groups are becoming scattered but the cortex is still relatively extensive. (*After Artschwager*, 1924.)

fleshy root, in cross-section, shows a narrow cortex covered with periderm and a central core of storage parenchyma, in which strands of vascular tissue are imbedded. The cambium separating these two regions is broken by the lateral root traces.

Flowers.—The sweet potato seldom flowers in continental United States, except in the extreme South. In the tropics, it flowers during December and January. Whether length of day or maturity of plant is the primary factor in inducing flowering at this time is not known. The flowers occur singly, or in an inflorescence of five or six, on stout, erect, axillary peduncles; in appearance, they resemble the morning

glory. They are 1 to 1½ inches in diameter. According to Thompson (1925), color varies somewhat in different varieties, being generally reddish; in only two out of 1,100 seedlings did white flowers occur. Five stamens of varying height are attached near the base of the corolla tube. Two of the stamens project beyond the stigma, facilitating self-pollination.

Thompson states that many plants which flower freely do not set seeds. Stout (1924) was unable to secure seed from flowers self-polli-

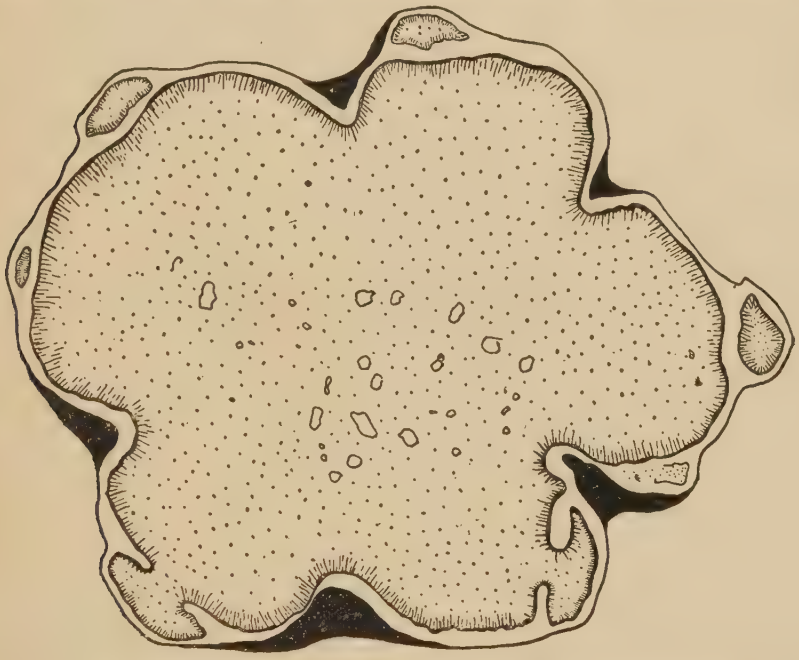

FIG. 43.—Cross section of mature thickened root of sweet potato, showing the projecting ridges or veins. (*After Artschwager*, 1924.)

nated by hand, though an abundance of apparently good pollen was produced. Wada (1923) made self-pollinations in 50 different varieties and found that two thirds of them were completely self-sterile; in the others, a variable degree of self-fertility existed. Crosses between self-sterile varieties did not result in seed formation; self-fertile × self-sterile, and the reciprocal cross, gave fruit setting in proportion to the fertility of the ♀ parent; self-fertile × self-fertile usually resulted in increased fertility but sometimes in complete sterility. Thus, it seems that seed production in sweet potatoes is limited not only by the rarity of flowering in temperate zones but also by the prevalent genetic self-sterility.

Seeds.—The seeds are borne in a round pod, or seed ball, one to four in each. They are black, flattened, or angular, and 3.3 millimeters in diameter. The hard, corneous, outer seed coat, which seems to be

impervious to water, may be responsible for delayed germination of many seeds. Thompson found that prompt germination was induced by filing a hole through the seed coat.

Climatic and Soil Requirements

Temperature.—The sweet potato requires a long, warm growing season. It grows best where the mean summer temperature is above 22°C. and the frost-free period not less than 175 days (Finch and Baker, 1917). Under favorable soil conditions, sweet potato culture exists in the United States farther north than the above limits would indicate. A growing season of 3½ to 4 months is sufficient to mature the earlier varieties, if the mean temperature is high. All parts of the sweet potato plant are sensitive to frost; plants subjected to hardening treatments have a slightly lower freezing point but are not rendered resistant to freezing. Harter and Whitney (1926) found that in plants held at a constant soil temperature of 10°C., the leaves turned yellow in 3 to 4 days and soon died. At 15°C., the plants remained normal, but no growth took place. Above 15°C., growth increased with the temperature up to 35°C. but decreased slightly at 38°C. This emphasizes the high-temperature requirement of the plant.

Sweet potatoes are often said to be drought resistant. This is true in that the plants are extremely resistant to desiccation and seem to suffer little permanent injury when exposed to prolonged periods of water deficit. The crop is grown successfully under irrigation in the warmer parts of the West.

Soils.—Light, sandy soils are generally considered best for sweet potatoes. Heavy soils, either because of their texture or their more abundant supply of nutrients or moisture, generally produce large, misshapen roots or only limited root development, with excessive growth of the vegetative parts. The detrimental effects of fine-textured soils seem to be more marked toward the northern limits of culture.

The sweet potato plant may be termed a good forager for nutrients. It often produces well without manures, on soils too low in fertility to produce satisfactory crops of other vegetables. On some of the long-cultivated, sandy soils in the East and South, however, sweet potatoes respond markedly to the application of various manures.

It appears from the results of Poole (1922), that sweet potatoes are tolerant of fairly acid soils. He found no increase in yield where lime was applied to soils of Ph 6.6 to 7, while the yield was increased where S was applied, making the soil more acid. The experience of growers in many sections indicates unfavorable effects from the application of lime, in that the roots grow too large and rough and are of a watery texture. This suggests that the influence of lime may be due to increased availability of N or other nutrients. The experiments, however, of Geise

(1925), in Maryland, on very acid soils which were also low in nutrients, show that under these conditions, lime greatly increased the yield without affecting the quality.

Cultural Practices

Difficulties in propagation by seed are increased by the fact that the vegetatively propagated varieties seem to be highly heterozygous and give rise to variable populations when selfed. Also, the yield of seedlings is generally below that of the parent variety.

Asexual propagation by three methods is practiced: The first (1) consists of planting small pieces of sweet potato roots directly in the field. This method has been abandoned generally, because of the poor stands

Fig. 44.—A vegetative sprout arising from the cambium of a sweet potato root, breaking through the cortex. (*After Miss Beals.*)

obtained and the excessive amount of seed potatoes required. A second method (2), which is the one usually practiced in the United States, utilizes sprouts which arise from sweet potato roots when these are placed in warm, moist soil. According to Beals (1923), the sprouts arise from the cambium of the fleshy roots. They generally break through the cortex in the vicinity of the lateral-root scars. They may arise any time suitable environmental conditions are supplied, as there is no natural dormant period in sweet potato roots. Sprouts are produced most abundantly at the basal end of the root. A third method (3) of propagation is by stem cuttings, or slips. Sections of stem 6 inches to 2 feet long are taken from plants early in the growing season and transplanted into moist soil. Roots, some of which become thickened into fleshy roots, develop promptly from the nodes below the surface of the soil. Many experiments in the South have shown cuttings to be equal or superior in productivity to sprouts. Extensive pruning of the early crop, however, to secure the vine cuttings may materially reduce the yield of the former. Vine cuttings are often used with the hope of securing seed potatoes free of root and stem-borne diseases.

Plant Growing.—Most of the sweet potatoes in the United States are grown from sprouts obtained by placing seed potatoes in a hotbed about one month before the beginning of the transplanting season. Sand is a better medium than loam; in sand, the plants are more easily pulled for transplanting, there is more abundant production of plants, less danger of disease infection, and better root production. Its advantages may be due to its limited supply of nutrients and its superior aeration. The most favorable temperature for sprout development is 27 to 30°C. Sprouts appear aboveground in about 2 weeks and are large enough for transplanting in 4 or 5 weeks after bedding. Sprout production is more or less continuous, however, and several crops of plants may be pulled from the bed at intervals of about 2 weeks. Experiments have shown the later pullings to be as vigorous and productive as the early ones.

FIG. 45.—A sweet potato "sprout" or plant, of the proper size for transplanting.

Roots from ¾ to 1½ inches in diameter are preferred for plant production. Small roots produce more plants for a given quantity and for a given area of hotbed space than large ones. Many experiments have shown no significant difference in the yield of plants from large *vs.* small roots. This is, of course, to be expected in vegetatively propagated clones in which mutations are rare. In practical seed selection, however, it is well to select the seed stock from high-yielding plants, chiefly to avoid the transmission of diseases likely to be present on the low-yielding units but also to preserve possible somatic mutations in the direction of high yield.

Transplanting.—The plants are hardened by withholding water and exposing to full sunlight and low night temperatures for a few days before transplanting. The stems are made more woody, and the plant tissues

more resistant to desiccation, conditions which enable them to withstand the transplanting. If the plants become too tall beforehand, a portion of the top may be advantageously sheared off. New growth then arises from axillary buds on the upper part of the stem. Sweet-potato plants may be shipped considerable distances if the roots are packed in wet paper or moss and the tops kept dry. Transplanting machines are used extensively in the setting of sweet potato plants.

The correct spacing of the plants varies somewhat, according to the variety and the soil conditions. Rows 30 to 34 inches apart, with the plants 15 to 18 inches apart in the row, are usual for the Jersey varieties. With varieties which tend to produce oversized roots and on very fertile soil, planting should be closer. Experiments in Mississippi, with the Nancy Hall variety, indicated that the yield per acre decreased regularly as the spacing in the row was increased from 7 inches upwards.

Manuring.—In southern Illinois, Durst (1916), in a 5-year test, obtained profitable increases in yield from stable manure and from P but not from K or N. Hotchkiss (1921), in a 3-year test in eastern Texas, found P and N to be important, while K did not affect the yield. In Florida, Scott (1920), in a 5-year test, found that K gave a three-fold increase in the crop, while N and P were without effect. Comparing potassium chloride and potassium sulfate, Scott obtained results slightly favoring the former. Voorhees (1892), in New Jersey, likewise obtained a greater increase in yield from the chloride than from the sulfate of potassium, while kainit proved injurious.

Experiments in Virginia by Johnson, Zimmerley, and Geise (1923) showed a 30 per cent increase in yield from an application of 1,000 pounds per acre of sodium chloride; the increases in yield were more marked on the crop dug early. Later experiments to determine whether Na or Cl was responsible for increased yield were inconclusive, although it was found that sodium sulfate, in addition to a fertilizer containing potassium sulfate, gave large increases in yield.

Stuckey (1914), in a 12-year test in Georgia, grew sweet potatoes continuously on the same plots, with annual applications of the manures. Table 42 gives a summary of the results.

Yields were depressed by the stable manure during the first 3 years of the experiment, but thereafter the yields with this treatment increased, while the phosphate and the check plots declined throughout the test. Nitrate of soda depressed the yield markedly the first 6 years, but there was an apparent recovery thereafter, probably because other nutrients were being exhausted, so that the N could not exert its depressing effect on production. In this experiment, a large vegetative growth accompanied a high yield, as indicated by the ratio of vines to roots. It appears also that the lack of nutrients in the check plot depressed vegetative growth much more than it did the development of the roots.

TABLE 42.—RESULTS OF SWEET POTATO MANURING EXPERIMENT, 1907 TO 1919
(*Stuckey*, 1919)

Treatment (per acre)	Yield in bushels per acre		Ratio of weight of vines to roots, 1913
	Average first 6 years	Average second 6 years	
Stable manure, 24 tons	183	248	2.80
Acid phosphate, 2,100 pounds	173	170	0.99
Sulphate of potash, 900 pounds	169	201	0.81
Nitrate of soda, 1,500 pounds	135	192	1.88
"Complete fertilizer," 1,800 pounds	196	261	1.54
Check, untreated	171	133	0.59

Stuckey determined the moisture, protein, fat, crude fiber, ash, sucrose, and "other carbohydrates" in the roots in the second and sixth years of the experiment. His conclusion was that there was little evidence that manures affected the chemical composition of the root. There were, however, some effects on quality, for the potatoes from the nitrate plot were of poor flavor and soggy in texture; those from the manure plot were most irregular and rough; and those from check, acid phosphate, and potash (the low-yielding plots) were smoothest and of the best quality.

Effect on Shape.—Schermerhorn (1923) found that where 1,200 pounds per acre of a "complete fertilizer" was applied, the yield increased with the per cent of K up to 8 per cent but that further increases in K resulted in decreased yield. An effect on form of the roots was also noted, the length decreasing and the diameter increasing with the amount of K applied.

TABLE 43.—EFFECT UPON SHAPE OF SWEET POTATO ROOTS OF VARYING AMOUNTS OF POTASSIUM AND NITROGEN IN 1,200 POUNDS PER ACRE OF "COMPLETE FERTILIZER"
(*Schemerhorn*, 1923)

Amount of potassium, per cent	Average length, inches	Average diameter, inches	Amount of nitrogen, per cent	Average length, inches	Average diameter, inches
0	5.90	1.66	2	5.83	2.09
4	5.60	2.06	4	6.00	2.05
6	5.39	2.24	6	6.11	2.14
8	5.47	2.19	8	5.64	1.87
..	....	....	10	6.06	1.92
..	....	....	12	6.80	1.93

Other workers have observed that where manuring increases the yield of sweet potatoes, the number of roots is not altered but the average size is increased. Apparently, this increased size is due to radial growth, at least when K is the element concerned. This is a fact of practical importance with such varieties as the Jersey, in which the roots tend to be long and slender. The opposite effect was observed from nitrogenous fertilizers, the diameter remaining about constant while the length of the roots increased as the amount of N applied was increased (see Table 43).

Quinn (1925) reports a similar relation between K and root shape in Missouri. There, no nutrient seemed to have any marked effect on total yield or vegetative growth, but the roots were more blocky and the yield of marketable potatoes increased, by potassium chloride. Quinn also found increased carbohydrate content in the roots where K was applied, as shown by the following table:

TABLE 44.—EFFECT OF MANURING UPON CARBOHYDRATE CONTENT OF SWEET POTATO ROOTS
(*Quinn*, 1925)

Treatment	Starch, per cent of dry matter		Total sugars, per cent of dry matter	
	1923	1924	1923	1924
Check	56.8	53.1	14.8	15.4
Nitrate of soda	56.3	54.9	15.3	14.0
Acid phosphate	61.3	55.8	17.2	16.8
Muriate of potash	68.3	65.7	18.4	17.9

Quinn suggests that the effect of K on shape of root is associated with its effect on carbohydrate synthesis.

Growth and Maturation.—Chemical changes in sweet potato roots during growth have been studied by Keitt (1911). The ratio of the various carbohydrates in potatoes harvested at different stages of development seems to depend considerably upon weather conditions. Glucose is the predominating sugar in fair, dry weather; and sucrose, in wet, cloudy weather. In general, total sugar content decreases during the growth period. The starch content is high in very young roots but decreases and remains low during the grand period of growth. This is probably because the carbohydrate synthesized during this period is being used largely in new tissue formation. The maturation period is characterized by further decreases in sugars, while starch increases to a maximum when the roots are physiologically mature. Following immediately after, hydrolysis of starch and increase of sucrose begin. This

after-ripening process sets in, whether the potatoes are left, attached to the living plant, in the ground, or are dug and placed in storage. Hasselbring and Hawkins (1915*B*) reached similar conclusions. Changes in moisture content are not marked during growth and maturation.

Keitt noted that sweet potatoes grown on sandy land had a higher starch content than those grown on clay soils. Also, important differences seemed to exist in the amount of carbohydrates in different varieties, though comparative analyses are open to question, in that the varieties may have been in different stages of maturity. In Table 45 is given a summary of the results on a few of the varieties studied.

TABLE 45.—COMPOSITION OF SWEET POTATO ROOTS AT HARVEST TIME IN PERCENTAGE OF FRESH WEIGHT
(*Keitt*, 1908)

Variety	Moisture	Total sugar	Starch
Nancy Hall	68.07	3.88	17.82
Pumpkin Yam	62.2	5.35	20.63
Southern Queen	68.4	3.69	19.07
Yellow Nancemond (Jersey)	72.1	5.14	13.50
Vineland Bunch (Jersey)	69.8	5.06	19.22
Red Jersey	71.8	5.59	16.42

The first three varieties named in the table, generally considered "moist fleshed," actually have a lower water content than the last three, which are often spoken of as "dry fleshed." Furthermore, the actual sugar content of the so-called "dry-fleshed" varieties is as high as or higher than that of the other group. Magoon and Culpepper (1922) find that the plasticity of the flesh of such varieties as Nancy Hall and Porto Rico is correlated with a high dextrin content, which develops shortly after harvesting but which is almost absent in the Jersey varieties.

STORAGE

Satisfactory methods for the storage of sweet potatoes are of comparatively recent development. The method of storing sweet potatoes in outdoor banks resulted in inferior quality, much decay by fungi, and frost injury. In 1902, Newman conducted an experiment in Arkansas, the results, in part, being as follows:

Not treated	61	per cent sound after 10 weeks
Packed in dry sand	54	per cent sound after 10 weeks
Rolled in sulfur	64	per cent sound after 10 weeks
Heated at 38 to 54°C. for 8 days	96.8	per cent sound after 10 weeks

(Average of five lots)

This successful curing by the use of high temperature was the forerunner of the modern method of storage. In 1913, Thompson published directions for the erection of sweet potato storage houses, and since that time, hundreds of such houses have been constructed in the South.

Management of Storage House.—Thompson (1918) recommends that sweet potatoes be cured at the beginning of the storage period by maintaining the temperature at 27 to 30°C. for 10 days or two weeks, at the same time giving good ventilation. Manns (1921) claims that sweet potatoes were satisfactorily cured at 21°C. for 3 to 4 weeks, with the relative humidity at 50 to 70 per cent. The combined effect of the heat and ventilation is to lower the relative humidity around the potatoes. This apparently causes a rapid "healing" of cut and bruised surfaces, which prevents the entrance of rot-producing organisms. The normal periderm of the roots is also thickened and toughened, qualities making it possible to handle them later with less injury. Thompson recommends a temperature of 10 to 13°C. for storage, after curing is completed. Temperatures below 9°C. are said to be injurious if long continued. Hasselbring and Hawkins (1915*A*) found that the roots rotted in about 6 weeks in cold storage at 4.5°C. Low temperatures for a short period, however, are not injurious, for Price (1923) exposed samples at 2.2 to 4.5°C. for 8 hours, at 0 to 1.7°C. for 8 hours, and at −1.4 to 0°C. for 6 hours without injury; −2.8°C. for 9 hours, however, caused some injury, and −4.4°C. for 6 hours resulted in complete decay. The decay, which results from prolonged storage at temperatures just above freezing, is probably due to lowered resistance to the soft-rot organisms. Wright and Taylor (1923) found the average freezing point in 20 varieties to be −1.28°C., with a range of .3°C. above or below this point, in different varieties.

Thompson and Beattie (1922) stored Big Stem Jersey, Nancy Hall, and Southern Queen at different temperatures for 164 days, after all had been cured at 27 to 30°C. The average results for each temperature are given in Table 46.

TABLE 46.—SHRINKAGE OF SWEET POTATOES STORED AT DIFFERENT TEMPERATURES
(*Thompson and Beattie*)

Temperature after curing	Loss during curing, per cent	Total shrinkage, in per cent of original weight at end of					Per cent loss from decay
		51 days	82 days	111 days	141 days	164 days	
10 to 13°C.	7.2	8.5	9.9	11.3	12.5	13.8	0.75
13 to 15.5°C.	8.3	9.5	11.2	12.5	14.2	15.7	0.67
15.5 to 18.3°C.	7.9	9.6	11.9	13.2	14.7	15.7	0.96

The shrinkage increases as the temperature rises, although the differences are not as great as might be expected. It is noteworthy that over one-half the shrinkage occurred during the 10 days or two weeks of curing.

The humidity factor in sweet potato storage has not received the attention it deserves. Probably a hygrograph is more essential to the management of a storage house than is a thermometer. While high humidity in the storage house favors the spread of rots, too low moisture content induces excessive shrinkage by water loss. Geise (1922) found that 60 to 70 per cent relative humidity at 13°C. was conducive to the best results. Under these conditions, shrinkage was only 8 per cent for a 5-months' period. The relative humidity is influenced by the amount of moisture given off by the potatoes, by atmospheric conditions outside the house, and by the temperature. Geise suggests that the ventilators be kept closed after the curing period, until the hygrograph shows a humidity of over 70 per cent. If outdoor conditions are dry, the humidity can be lowered by opening the ventilators or, if the weather is wet, by raising the temperature in the house.

Other Factors in Storage.—The amount of decay in storage is decreased by careful handling. Thompson and Beattie (1922) found an average loss of 7.5 per cent by shrinkage and 0.45 per cent by decay where the roots were carefully handled, compared to 10 per cent loss by shrinkage and 3 per cent by decay in commercially handled roots. Cut or bruised potatoes show an excessive amount of shrinkage and a greatly increased loss from decay, even when stored under good conditions. Johnstone (1925) reports an increase of 97 per cent in respiration as a result of wounding, accounting for much of the increased shrinkage. Sorting the potatoes in storage also leads to increased loss from decay, even when the process is carefully performed. Varieties differ in their adaptability to storage; thus, Thompson and Beattie (1922), who carried on extensive storage tests with 27 varieties, found that the Gold Skin was a very poor keeper while other varieties of the Jersey group kept well for only a short storage period in many cases, developing an internal breakdown and shriveling at the tips after about two months. Such varieties as Triumph, Nancy Hall, and Southern Queen showed the least shrinkage after 160 days' storage. These varieties have been kept for over a year in good edible condition. Storage in bins 5 feet deep results in slightly less shrinkage than storing in crates or hampers; this is partly balanced by a slightly larger amount of decay in bin storage. Storage in crates is to be preferred, since it eliminates one handling of the roots and provides somewhat better conditions for curing. Stuckey (1919) tested the keeping quality with reference to the manures used in growing the crop. He concluded that there was no consistent relationship, except that the amount of infection by black rot was greatest in the product from the acid-phosphate and nitrate plots.

Changes Taking Place during Storage.—One of the most important considerations is the loss in weight, or shrinkage. Stuckey (1919) observed a shrinkage of 16.6 per cent in a storage period of 4 months. The loss in moisture was determined to be 3.7 per cent, leaving the major portion, 12.9 per cent, to be accounted for in some other way. The destruction of carbohydrates through respiration probably accounts for much shrinkage.

Moisture.—Thompson and Beattie found over half of the shrinkage for the entire season to occur during the curing process, which has been assumed to involve chiefly the elimination of water from the potatoes. Hasselbring and Hawkins, however, (1915), found the actual decrease in water content to be only 0.5 per cent in Jersey and 3.2 per cent in Southern Queen in the first 18 days of storage, which included the curing period at 27°C. Magoon and Culpepper (1922) found a loss ranging from 0 in Nancy Hall to 2.5 per cent in Southern Queen. Hasselbring and Hawkins (1915) found little change in moisture content during storage from October 20 to the following June (see Table 47). Southern Queen showed a somewhat greater decrease than Jersey. Actual water loss is probably compensated for in part by that formed in respiration. Johnstone (1925) concluded that the changes which take place during curing are largely physiological and marked by an increase of respiration for a few days after harvesting, which reaches a maximum and then falls to a constant rate. These changes seemed to take place regardless of the temperature during the curing period but were more rapid at 30°C. (slightly above the usual curing temperature). Though an appreciable loss in weight occurred, there was little difference in the percentage-moisture content. Johnstone showed also that the production of shoots during the curing process is simply a response to the temperature and moisture conditions which prevail and is not an indication that the curing process is completed, as has sometimes been assumed.

Carbohydrates.—Harrington (1895) first observed that important transformations in the carbohydrates occurred during the storage period. In 16 varieties stored 4 months, he found that on the average, reducing sugars increased from 3.2 to 4.6 per cent and sucrose, from 3.1 to 7.7 per cent during this period. Shiver (1901) obtained similar results, observing also a concomitant decrease in starch. Miyake (1915), who studied the nature of the sugars in sweet potatoes, concluded that the reducing sugars consisted of both dextrose and levulose and the non-reducing sugar of sucrose. He did not find any pentose, galactose, mannose, or maltose.

Hasselbring and Hawkins (1915) studied the changes during curing at 27°C. for 10 days and in subsequent storage at 11.7 to 16.7°C., in two varieties. More importance should be attached to their results than to those of earlier investigators, because their method of preparing samples

was safer and their data are calculated to the original moisture content of the potatoes, thus eliminating a source of error. Their starch figures, however, really represent acid-hydrolyzable polysaccharides, whereas Keitt (1909) determined starch by malt-diastase digestion. Table 47 gives a summary of their results, the first sample being taken at harvest time.

TABLE 47.—CHANGES IN COMPOSITION OF SWEET POTATO ROOTS DURING STORAGE (*Hasselbring and Hawkins*, 1915)

Date	Variety: Big Stem Jersey					Variety: Southern Queen				
	Water	Starch	Sucrose	Reducing sugars	Total sugars	Water	Starch	Sucrose	Reducing sugars	Total sugars
Oct. 20	73.5	19.1	1.9	0.9	2.9	71.7	22.1	1.2	0.4	1.6
Nov. 8	73.0	16.9	3.5	1.3	5.0	68.4	19.9	3.0	0.8	3.9
Dec. 6	71.9	16.4	3.9	1.4	5.5	67.7	19.3	3.5	0.7	4.4
Jan. 4	72.1	16.0	4.4	1.3	5.9	67.5	19.7	3.5	0.7	4.5
Feb. 1	72.2	14.1	6.1	1.6	8.0	68.0	19.2	4.0	0.6	4.8
Mar. 1	72.0	13.1	7.0	1.4	8.8	68.0	19.0	4.1	0.5	4.8
Mar. 20	73.0	13.4	6.4	1.1	7.8					
Mar. 26	72.5	14.5	5.6	.9	6.8					
Apr. 16	72.9	14.2	6.0	.9	7.2	66.7	20.3	2.9	0.5	3.6
May 4	....	....	...	...	...	69.2	19.8	3.4	0.5	4.1
June 1	72.4	14.6	5.8	.9	7.0	68.1	20.1	2.8	0.5	3.5

Reducing sugars show no important variations; they are probably transition products which do not accumulate in any great amount under normal conditions. Most striking is the sudden increase in sucrose at the beginning of the storage period, followed by a more gradual increase in the ensuing 4 months. During this period, there is a decrease in starch. The sugar content in both varieties reaches a maximum about Mar. 1 in both varieties; thereafter, some of the sugar is reconverted to starch. This period evidently marks a turning point in the balance of the physiological processes in the sweet potato.

Hasselbring and Hawkins also stored sweet potatoes at 4°C., where the starch-to-sugar transformation proceeded much more rapidly than at higher temperatures; the total amount of sugars formed was also greater at the low temperature. These results are attributable in part to the slowing up of respiration, with resultant conservation of sugars, and in part to a shifting of the starch-sugar equilibrium point at the lower temperature, so as to allow a greater concentration of sugar. Sweet potatoes always decayed at 4°C., however, before carbohydrate equilibrium was attained. Later studies by the same authors (1915*A*) indicate that in the carbohydrate transformations, starch is first converted to reducing sugar, which is, in turn, condensed to sucrose.

Magoon and Culpepper (1922) found that when canned after curing, much of the starch had been converted to dextrin in the moist-fleshed varieties. Table 48 gives their analysis of the product canned at different stages.

TABLE 48.—COMPOSITION OF SWEET POTATO ROOTS CANNED BEFORE AND AFTER CURING

(*Magoon and Culpepper*)

Variety	Stage canned	Moisture content	Total sugar as dextrose	Total polysaccharides as starch	Dextrin
Big Stem Jersey	Freshly dug	72.6	8.65	10.85	0
	After curing 10 days	71.5	9.80	10.31	0.41
	After storage 10 days	71.2	10.62	10.39	
	After storage 20 days	70.4	10.62	10.36	0.46
Southern Queen	Freshly dug	71.1	9.05	10.14	0.17
	After curing 10 days	68.6	11.92	9.53	1.33
	After storage 10 days	68.5	12.10	10.14	4.73
	After storage 20 days	68.6	12.09	9.06	3.78
Nancy Hall	Freshly dug	66.8	11.06	11.02	0.32
	After curing 10 days	66.8	13.99	8.51	4.78
	After storage 10 days	64.6	15.08	9.21	5.18
	After storage 20 days	65.1	15.03	9.14	5.11
Porto Rico	Freshly dug	70.0	8.58	11.06	0
	After curing 10 days	69.1	13.78	7.65	3.92
	After storage 10 days	68.8	13.63	8.44	3.88
	After storage 20 days	68.2	13.74	9.13	3.66

There is little or no dextrin when the roots are canned at harvest time. In the dry-fleshed Jersey, very little dextrin forms during storage. On the other hand, the moist-fleshed Nancy Hall and Porto Rico varieties show a large amount of dextrin at the end of the 10-day curing process. In the Southern Queen, dextrin formation is slower but eventually becomes as great as in the others. This accords with the common idea that the Southern Queen is dry fleshed and mealy early in the season, becoming more plastic toward the latter part of the storage period. The roots become sweeter during storage because of increase in sugars, and certain varieties also become more plastic because of increase in dextrin.

MARKETING

Producing Regions.—The shipping season and the carlot movement for the leading sweet potato-producing states is given in Table 49. Southern states, which have the largest acreage, are not the most important shippers of sweet potatoes, while states in the northern range of the sweet-potato belt supply most of the shipments. In 1922, 11 southern

states produced 146,360 carloads but shipped only 4,020 cars, less than 3 per cent of their crop; 16 border states produced 26,276 carloads and shipped 11,353 cars, about 45 per cent of their total production. The border states are situated more advantageously with reference to the larger markets, hence produce a large proportion of the crop for shipment. The southern states produce chiefly for local consumption. Until recently, the border states had made greater development in modern storage facilities and so were in a better position to ship during the winter. In recent years, however, many storage houses have been built in the South, which is becoming an important factor in late winter shipments. The varieties grown in the South have not been popular on northern markets, because consumers there have been accustomed to use the dry, mealy, Jersey type, which is shipped from the border states.

TABLE 49.—SHIPPING SEASONS AND CARLOT MOVEMENT OF LEADING SWEET POTATO-PRODUCING STATES

State	Shipping season	Carlot movement				
		1922	1923	1924	1925	1926
Alabama	July to August	585	407	542	765	587
Arkansas	November to April	466	292	370	296	472
California	August to February	936	862	484	948	1,047
Delaware	November to April	1,753	2,737	1,419	1,861	1,710
Georgia	July to March	1,246	827	902	837	580
Louisiana	September to May	1,019	774	596	1,646	1,532
Maryland	September to March	1,518	1,614	1,018	1,568	1,857
New Jersey	September to April	2,513	2,262	1,745	1,453	1,519
North Carolina	August to April	721	654	720	1,189	1,320
Tennessee	August to May	1,448	1,472	789	1,697	2,865
Texas	August to April	930	739	302	311	538
Virginia	August to December	6,636	5,436	5,188	4,734	6,428
United States total		20,715	19,107	14,853	18,571	21,675

Shipping Seasons.—The earliest shipments, about July 1, are from the Coachella Valley of California and from the Gulf states. Prices are usually high on the extra-early crop but decline as shipments increase. About the middle of August, heavy shipments begin from the eastern shore of Virginia and a little later, from Delaware, Maryland, and New Jersey. September and October are the heaviest shipping months, and prices are usually low during this period, when the potatoes are being shipped direct from the fields as they are dug. The crop intended for storage is allowed to grow until full maturity is reached or until the plants are partly killed by frost. The storage crop is harvested in late October and early November. Field shipments supply the markets until about

Thanksgiving time. Prices usually rise during the holiday period, and the stored product begins to appear on the market. The border states ship most of their stored sweet potatoes by January, while the South ships chiefly in late winter and in spring, when higher prices enable shippers to send profitably to northern markets. The volume of carlot shipments declines gradually through the winter, only a few cars being moved after Apr. 1. In 1922, there were over 3,000 storage houses for sweet potatoes in the United States, with a combined capacity of 12,000,000 bushels, or about 15 per cent of the average annual crop.

Grades.—The essential points in the U. S. grades for sweet potatoes are as follows:

U. S. Grade No. 1 consists of clean roots, free of decay, bruises, cuts, cracks, frost, and insect or disease injury. The sweet potatoes must be at least 1¾ but not over 3½ inches in diameter and from 4 to 10 inches in length.

U. S. Grade No. 2 consists of sound potatoes free of serious damage by any of the defects listed under U. S. Grade No. 1 and must be from 1½ to 3½ inches in diameter.

U. S. Jumbo Grade consists of sound potatoes free of serious defects of any sort and over 3½ inches in diameter. Such large potatoes are seldom in demand on the market and are usually disposed of at harvest time for canning or for stock feed.

Roots less than 1½ inches in diameter are used for seed purposes or are canned.

Canning.—Sweet potatoes were probably first canned in 1885, in New Jersey, according to McHatton (1915). They are now canned on a large scale. One of the difficulties in canning is a discoloration of the pulp, apparently due to oxidation. McHatton found that this could be prevented by removal of air through thorough exhausting and by quick cooling after processing. Magoon and Culpepper (1922) found that varieties differed in the tendency to discolor in canning. The variety Gold Skin was found to be the best of the Jersey group from the standpoint of color and texture; Dooley and Porto Rico were the best of the richly colored, moist-fleshed varieties, while Belmont and Strassburg were the best of the light-colored, moist-fleshed type. Varieties of Jersey, which are of paler color than Gold Skin, are now used mostly for canning. Sweet potatoes are usually canned soon after harvesting. The quality for canning is much better, however, if they are cured at 27 to 30°C. for 10 days before canning and still better if held 10 to 20 days longer, in storage at 10 to 13°C.

Other Uses.—A high-grade glucose syrup can be made from sweet potatoes, according to Gore (1921), utilizing the natural diastase of the root to hydrolyze the starch. Even in ordinary baking, Gore (1923) states that most of the starch is broken down to maltose; hence, when

baked, they are not a starchy food, most of the carbohydrate occurring as soluble sugars.

A method for the manufacture of starch from sweet potatoes was developed by McDonnell (1908). Only 55 to 60 per cent of the starch was extracted by his method, however. From present knowledge of the carbohydrate changes in sweet potatoes, the roots should be used for starch manufacture at about the time of physiological maturity, when starch content is highest. Some of the heavy-yielding varieties, which are of poor table quality, may become useful. Thus, according to Keitt (1909), Brazilian produced 4,148 pounds and Southern Queen, 4,443 pounds, of starch per acre, compared to 2,694 and 1,483 pounds, respectively, for Nancy Hall and Vineland Bunch varieties. Sweet potatoes are a potential raw material for the manufacture of alcohols and many other technical products.

Both roots and tops have considerable value as feed for livestock, either in the fresh or in the dried condition. The composition of fresh roots and dry tops, as determined by Keitt, is given in Table 50.

TABLE 50.—PROXIMATE ANALYSES OF SWEET POTATO ROOTS AND TOPS (AVERAGE OF 14 VARIETIES)

	Moisture, per cent	Protein, per cent	Fat, per cent	Crude fiber, per cent	Ash, per cent	Nitrogen-free extract, per cent
Roots, fresh	68.1	1.6	0.5	0.9	1.0	27.9
Tops, dry	....	12.5	4.9	18.2	8.7	55.7

The green vines are often gathered just before harvesting the crop and fed to cattle. The small roots and strings, as well as injured potatoes, are used for hog feed.

VARIETIES

American varieties of sweet potatoes were classified by Thompson and Beattie (1922) into seven major groups, which contain varieties nearly or quite the same. The following is the key to these groups:

I. Leaves deeply lobed or parted:
   1. Purple stain at base of leaf-blade, *Ticotea-kaoli group.*
   2. Leaves without purple stain at base, *Belmont group.*
      (*a*) Belmont section, vines long and creeping.
      Belmont, Georgia, Eclipse Sugar Yam, Vineless Pumpkin Yam, Yellow Yam.
      (*b*) Bunch section, vines very short and bushy.
      Gros Grandia, Vineless, Bunch Candy Yam.

II. Leaves not deeply lobed or parted:

1. Purple stain at base of leaf-blade.

A. Stems purple or greenish with decided purple tinge, *Spanish group:*

(*a*) Yellow Spanish section, roots light to russet yellow. Pierson, Yellow Strassburg, Yellow Spanish, Triumph.

(*b*) Bermuda section, roots yellow, splashed with pink to purple, irregular in shape.

Red Bermuda, Porto Rico, Key West Yam, Creola.

(*c*) Red Spanish section, tubers deep red and smoother and more regular than the rest of this group.

Red Spanish, Dahomey, and Purple Yam or Nigger choker.

B. Stems green:

(*a*) Leaves entire to slightly shouldered, roots white. *Shanghai group.*

Shanghai (Early Golden, California), Minnet Yam.

(*b*) Leaves with 6 to 10 marginal teeth. Roots salmon pink. *Florida group.*

Florida, Nancy Hall, and General Grant Vineless.

2. Leaves without purple stain at base.

A. Stems purple, *Southern Queen group.*

White Yam, Southern Queen (Hayman) Cuban, Miles Yam.

B. Stems green.

(*a*) Stem medium to large, roots yellow, tinged with pink, *Pumpkin group.*

Pumpkin Yam, Norton, Dooley.

(*b*) Stems slender, roots fusiform, russet, yellow, or red, *Jersey group.*

(1) Red Jersey Section, roots red.

Red Jersey (Red Nancemond, Early Red Carolina, Japan Brown.

(2) Yellow Jersey section, roots yellow.

Vineland Bunch, Big Stem Jersey, Yellow Jersey, Yellow Nancemond, Gold Skin.

The more important commercial varieties are briefly discussed below.

Yellow Jersey.—Several strains of this variety are much grown in New Jersey, Maryland, Virginia, and California. It is the leading type for shipping purposes. The roots are uniform in shape, being either a long or a short spindle, depending on the strain. The skin is russet yellow; the flesh, creamy white. The tendency is to form many roots per plant. The flesh is rather dry and mealy, and storage quality is not of the best.

Nancy Hall.—This is the leading variety in the central South. It is popular on all markets except those in the Northeast. The Nancy Hall

is an excellent variety for storage and is best known on the markets as a late-winter potato. The roots tend to grow too large and are sometimes rough. The number per plant is small. In color, the roots are white irregularly overspread with light pink. The flesh is pink in color; and when cooked, the texture is soft and plastic.

Porto Rico.—This variety is most important commercially in the South Atlantic states and is replacing Nancy Hall in sections farther west. In eating and storage qualities, it resembles the Nancy Hall but the plants are more vigorous and more productive. The roots are copper red in color and are inclined to be variable in shape.

Southern Queen.—Since white-skinned types are not wanted by consumers, this excellent variety is declining in importance commercially.

FIG. 46.—Typical mature roots of the 3 leading commercial varieties of sweet potatoes. A. Nancy Hall. B. Big Stem Jersey. C. Porto Rico.

Southern Queen is one of the heaviest-yielding varieties, an excellent keeper under rather unfavorable conditions, and very resistant to stem-rot disease. The roots are short-oval in shape, smooth, and rather large, with a clear-white skin and yellowish flesh.

BREEDING

Considerable interest has developed recently in the propagation of new varieties from seedlings, but little systematic breeding work has been done. Wada (1923) reports that green color of stems and white color of skin and flesh are dominant characters and segregate in 3:1 or 15:1 ratios in crosses with the recessive (colored) allelomorphs. In seedlings resulting

from open-pollinated seed, Thompson (1925) reports extreme variability, part of which was probably due to cross-pollination. Considerable variation in the progeny of close-fertilized seeds was also observed. One of the most variable characters observed in seedlings by Thompson was the production of thickened roots, which varied from almost nothing to more than the parent variety. The yield of the seedling the first year was found to be not a reliable index of productivity of the vegetatively propagated clone arising from it.

Some varieties have probably arisen as somatic mutations. That such variations occur in sweet potatoes and are transmissable through vegetative propagation has been shown by Rosa (1926) and by Harter (1926). Rosa found yellow, white, and striped roots on one plant of the Jersey variety. The yellow- and white-skinned potatoes reproduced their own kind the following year, and the same was true of the yellow and white portions of the striped potato. Since the sprouts used in propagation come from tissues deeper seated than the epidermis, it is evident that mutation must have affected these tissues. Harter found yellow and red roots on a plant of the variety Haiti, which normally has red roots only. The roots of both colors reproduced their own kind; there was no difference between the strains, except in color.

Efforts to obtain high-yielding strains by selection and to isolate strains having some particular shape of root have not been successful, though few such efforts have been reported. Evidently such characters as yield and root shape are much influenced by the immediate environment and the variations observed are not heritable, at least in the great majority of cases. However, roots of typical shape for the variety are produced in different parts of the country.

Diseases

Black Rot (*Ceratostonella fimbriatum*).—This is probably the most widely distributed and most destructive field disease of the sweet potato. All underground portions of the plant are attacked. On the fleshy roots are produced black, sunken, irregular surface lesions, originating often in a growth crack or at a point injured by some other agency. The spots may remain small or spread until nearly the whole root is involved. On the underground stem occur similar black spots, which may enlarge until the whole stem is rotted off. Infection of plants when drawn from the plant bed is often noticeable in a blackened area on the basal portion.

The fungus overwinters in the soil and in infected potatoes; it has been disseminated by shipments of diseased seed and plants. When infected roots are bedded for plant production, the sprouts arising therefrom become infected. Such plants are often killed before or soon after transplanting, while others may survive until the end of the season,

producing a crop of small roots, which are likely to be infected. The progress of the disease in the plant probably depends on environmental conditions. Sometimes nearly all of the infected plants die within a few weeks after transplanting; at other times, nearly all survive. Harter and Whitney (1926) found 100 per cent infection at temperatures of from 15 to 30°C., the usual range of soil temperatures during the growing season. The extent of the infection of individual plants was found to decrease above 25°C., with no infection at 35°C., though the plants themselves thrived at this temperature. Hence, the disease could be controlled, in the plant beds at least, by keeping the soil temperature high. The same workers showed that infection increased with the water content of the soil, up to 60 per cent of the water-holding capacity. Lauritzen (1926) found that infection of the fleshy roots in storage could take place between 9.5 and 33.4°C. Enlargement of lesions already formed occurred at temperatures as low as 6°C. Uninfected potatoes may be kept in storage at 10 to 12°C. in the presence of the fungus without becoming infected, but if infection has already taken place, the lesion will continue to spread. Even though visible lesions are not apparent at harvest time, they may develop very abundantly in storage, according to Harter, *et al.* (1926). Black rot is the cause of extensive losses in storage, and even small lesions render the sweet potato inedible, because the fungus produces a bitter substance, which permeates the whole potato when cooked.

The control of black rot is accomplished by a combination of the following preventive measures: (1) selection of seed free of black-rot lesions, (2) disinfection of the seed potatoes (3) use of uncontaminated soil or sand in the plant bed, (4) avoiding, in the plant bed or in the field, the use of manure, which may have been contaminated by diseased potatoes, (5) crop rotation.

Seed Treatment.—Disinfection of seed roots prior to placing them in the hotbed is necessary in the control of several diseases. Treatment is given at bedding time. If the seed stock is treated in the fall, when placed in storage, much decay results before the winter is over. Mercuric chloride, at the rate of 1 ounce to 8 gallons of water, is the disinfectant usually used. An immersion of 10 minutes is sufficient, and longer immersion causes injury. Aside from the production of disease-free plants, Taubenhaus and Manns (1915) claim a stimulating effect on plant production. They found that formaldehyde at the usual dilution is not effective against sweet-potato fungi but is toxic to the roots.

Weimer (1921) showed that there is a progressive reduction in the strength of mercuric-chloride solution, with the immersion of successive lots of roots. Some of the mercuric chloride is absorbed by the roots, and some is lost, due to precipitation by soil adhering to the roots and to absorption by the container used. Burlap sacks absorb large amounts.

Cotton sacks or wooden baskets should therefore be used in soaking the seed. Weimer found that for an original volume of 32 gallons, 0.5 ounce of mercuric chloride should be added after each 10 bushels treated, with enough water to restore the solution to its original volume.

Stem Rot (*Fusarium hyperoxysporium* and *f. batatatis*).—This disease is often referred to as "blue stem" because of the discoloration of the underground portion of infected stems and as "yellows" because of the characteristic color of the foliage in infected plants. The fungus invades all parts of the plant, being confined particularly to the vascular system. Infected stems are blackened inside, and the leaves turn yellow, then die. In the fleshy roots, a brownish discoloration of the vascular tissue is often, but not always, apparent near the stem end. Sprouts from such roots are likely to be diseased.

As stem rot is transmitted in the roots of infected plants, the most important control measure is to select seed stock from disease-free plants at harvest time. Only high-yielding hills should be considered; even these may be infected, but this question may be determined by splitting the main stem of the plant, which, if infected, is brownish within. An important aid in securing healthy seed is to grow it from vine cuttings; cuttings should be taken only from healthy plants. Seed disinfection and the other sanitary precautions mentioned under black rot (p. 286) are also advisable. It is known that the stem-rot fungus can survive in the soil for several years and that plant infection can take place through the roots. When soil is once infected, sweet potatoes should not be grown for at least 5 years. No other host plant is known.

Important differences exist in the susceptibility of different varieties to stem rot. Poole (1924) found that White Yam, Red Brazil, and Triumph were immune, while Dooley, Porto Rico, and Nancy Hall were moderately susceptible. Most strains of the Jersey variety were very susceptible, though some showed considerable resistance. Thus, the per cent of plants killed by stem rot ranged from 13 to 61 per cent. The most resistant strain produced 233 bushels per acre, the most susceptible, 115 bushels. Poole found no evidence that immune strains could be developed by plant selection, however.

Where the market demands exclusively the susceptible varieties and where soil infection is so extensive that healthy seed does not prevent severe loss, Poole (1926) finds it a good practice to set two plants in a hill. Doing this increases the cost of planting an acre, but the practice seems profitable. If one of the plants dies of stem rot, the other may live and produce a full crop. If both survive, the production exceeds that of a single plant. These results were secured with the Jersey, Nancy Hall, and Porto Rico varieties set 24 to 30 inches apart in rows spaced 30 to 36 inches. Even with three plants per hill, all surviving to the end of the season, the yield of marketable potatoes was increased over single plants.

Foot Rot (*Plenodomus destruens*).—Infection first appears as small brown to black spots on the stem near the soil line. The stem is eventually girdled, and the lesion extends somewhat above the soil. The plant wilts and generally dies by late summer. Even though considerable vegetative growth is made, few or no potatoes are formed on affected plants, since the flow of carbohydrates to the roots is prevented. Infection from the soil may occur on the roots of healthy plants; the result is a firm, brown rot.

Plant infection may take place in the hotbed from infected seed or soil and also in the field from the latter. The control measures are the same as for black rot.

Scurf (*Monilochaetes infuscans*).—Although the fungus grows on the stems, no apparent injury results, either in plant bed or field. On the roots, a superficial, brownish discoloration is produced, which injures their appearance; in extreme cases, cracking and distortion of the roots may occur. Control measures are the same as for black rot. The presence of large amounts of organic matter and excessive moisture in the soil seems to favor the development of the scurf fungus. Poole (1923) found that scurf was controlled by the application of 200 to 400 pounds of S per acre, under New Jersey conditions.

Root Rot (*Ozonium omnivorum*).—The same fungus causes the Texas root rot of cotton and alfalfa. It occurs only in the southwestern states. Soils known to be infected should not be planted to sweet potatoes. No control measures are known.

Soil Rot, or Pox.—This disease was originally attributed by Halstead (1890) to the fungus *Acrocystis batata*, but Elliott (1916) seemed to find it associated with a slime mold, *Cystospora batata*. Only the underground parts are attacked. The fibrous roots are destroyed in part, and on the fleshy roots, dark, dry spots occur, which, through the decay of the tissue, develop into pits. Constrictions leading to irregular development of the roots also occur. The disease is soil-borne and may persist there for over 10 years but is not transmitted in plants grown from diseased roots. Poole (1922) found that applications of S, at the rate of 200 to 600 pounds per acre, which made the soil more acid (Ph 5.3 to 6.0) than the checks (Ph 6.6 to 7.0) increased the yield considerably and greatly reduced the per cent of infected potatoes.

Soft Rot (*Rhizopus spp.*).—Soft rot occurs chiefly in storage, although some decay from this cause often appears in the field and in the plant beds. Decay begins usually at a wound, and often the whole potato becomes soft and watery. Later, the decayed potatoes become hard and dry. Under humid conditions, the fungus forms a dense white mold on the surface of decayed potatoes, and after a few days, this may be covered with the sooty, black spores. Rhizopus spores are usually in the air everywhere. Lauritzen and Harter (1923*A*) find that there are several

species of this fungus capable of causing soft rot but that only two species, *R. tritici* and *R. nigricans*, ordinarily do so under storage conditions. The former species causes the decay at temperatures above 30°C.; the latter, between 6 and 20°C.; and both, between 20 and 30°C. There is no temperature suitable for sweet-potato storage outside the range of these two species. Below 6°C., sweet potatoes are rapidly decayed by another fungus, *Mucor*.

The rapid decay of sweet potato and the soft, watery texture resulting from infection by *Rhizopus*, is due to the secretion of an enzyme—pectinase—by the fungus. This enzyme dissolves the pectic materials of the middle lamella, the cells separate, and the tissue is reduced to a mushy mass. Sweet potatoes decaying from soft rot develop a sour odor, which Edson (1923) found to be due to alcohol-acetic-acid fermentation.

Soft-rot organisms are unable to enter sweet-potato roots through the normal, uninjured periderm. Cuts, other disease lesions, and small abrasions in the skin furnish the infection centers. Probably the weakening of the living tissues through exposure to low temperatures or other unfavorable conditions lower resistance to invasion. Harter and Weimer (1921*B*) found that *R. tritici* and *R. nigricans* are parasitic on all of the common varieties but that Nancy Hall and Southern Queen are very resistant to decay, while most of the Jersey varieties, Belmont, and Dooley are very susceptible. A group intermediate in resistance includes Porto Rico, Big Stem Jersey, and Triumph.

The control of soft rot involves careful handling to prevent wounds, prompt disposal of potatoes cut or otherwise injured in harvesting, harvesting before the roots have been injured by freezing or by prolonged exposure to cold, wet weather; prompt curing, to hasten the corking over of small abrasions, and regulation of the humidity and temperature in the storage house. Lauritzen and Harter (1923*B*) found that at 23°C., only a small percentage of cut roots could be infected at the high relative humidity of 94 to 98 per cent. The infection increases as the humidity is lowered, becoming almost 100 per cent at 72 to 84 per cent relative humidity. Decrease in the humidity below this range results in a decrease of infection, which was only 20 per cent at 49 to 52 per cent relative humidity. The same relation of humidity to infection prevails at 12°C., but the range for infection is narrower. Apparently, the maintenance of a low humidity in the storage house during the curing period is justified, in so far as prevention of soft rot is concerned.

Ring Rot.—This type of decay occurs in storage only and is caused by the same organisms as is soft rot. The infection point is on the side of the potato, and the collapse of tissue, for some unknown reason, is confined to a ring around the root. The lesion becomes dry, hard, and sunken. Prevention of ring rot is the same as for soft rot.

Dry Rot (*Diaporthe batatatis*).—This is another type of decay occurring in storage. Infection begins at the stem end and gradually invades the whole root, producing a firm decay. Later, it becomes mummified, hard, dry, and covered with small pimples, in which the fungus spores are found. The decayed tissues turn black. The dry-rot fungus is widely distributed, and the aboveground stems may be infected in the field, where the root infection probably begins also.

Root Knot (*Heterodera radicicola*).—Sweet potatoes are usually considered relatively immune to this, the common garden nematode. Profitable crops of sweet potatoes can be grown on soils so infested with nematodes that most vegetables are killed. Galls on the fibrous roots are seldom conspicuous. On the basal part of the fleshy roots, nematode invasion may be followed by superficial decay. Elliott (1918) found that nematodes may be disseminated in infested roots or in plants grown in infected soil, even though no evidence of their presence is visible. No method of seed treatment is known which will kill the nematodes in the fleshy roots.

Weimer and Harter (1925) found the Nancy Hall and Red Bermuda varieties to be relatively susceptible to nematodes, whereas several others, especially the Porto Rico variety, were highly resistant.

Mosaic.—A typical leaf-mottling mosaic, accompanied by dwarfing and reduction in yield, was discovered in Arkansas in 1919. It has since been seen in several other states, always in the Nancy Hall variety. This mosaic may increase from year to year, where no selection is practiced, for it is transmitted through the roots, and roots produced by mosaic plants are small, such as are usually used for plant propagation. Rosen (1926) found that this mosaic can also be transferred from plant to plant by juice inoculation though an incubation period of at least 12 months is required. The removal of the affected plants from the field during the growing season or from the plant bed before transplanting will control the trouble.

Insects

Sweet-potato Weevil (*Cyclos formicarius*).—This is the only insect causing serious damage to sweet potatoes. It occurs in the Gulf states, and, except in Texas, it is limited to coastal districts. There is danger of its spread to other sections, however. The adult beetle is ¼ inch long, with metallic, dark-blue wing covers. It feeds on leaves, stems, and roots of the sweet potato. The females lay eggs on the stems and roots in the field, and these hatch in storage, where the larvae and the adults do extensive damage. Larvae hatching in the stems tunnel down to the roots. Infested roots are tunneled in all directions and are worthless.

This weevil also feeds and breeds on common morning glory, bindweed, and the perennial beach morning glory. Destruction of these plants and

of all infested vines and roots of the sweet potato is recommended by Chittenden (1919) as the chief control measure. The plant bed should be located as far as possible from the field, and the remaining mother roots and plants destroyed when the plant-setting season is over, thus eliminating an important breeding place of the weevils. Hogs may be used to destroy weevil-infested plants and roots. The weevils move very slowly from place to place, unless transported within infested roots.

Slightly infested roots may be disinfected in the storage house with carbon bisulfide, though the concentration used and the time of treatment have to be carefully controlled, to avoid injury. The weevils feeding on the vegetative parts of the plant, either in the plant bed or in the field, can be controlled by spraying with arsenicals. The use of seed roots or of plants from a weevil-free locality is desirable.

Several other insects, which generally cause only minor injury to sweet potatoes, have been described by Smith (1910). The sweet-potato flea beetle is a distinct species from the common, or potato-flea, beetle. Goldbugs, or tortoise beetles, are sometimes destructive to the leaves early in the season.

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PART X

SOLANACEAE

The *Solanaceae*, or nightshade family, contain several species used as vegetables, the most important being potatoes, eggplants, tomatoes, and peppers. Tobacco and belladonna are important drug plants; species grown as ornamentals include *Petunia* and some of the *Nicotiana;* others are common, native weeds. The *Solanaceae* are native chiefly of tropical regions, both of the Old World and of America; many species, however, are found in temperate zones. Some members of this family are noted for the production of deadly poisons, or alkaloids.

CHAPTER XVIII

LYCOPERSICUM

The tomato is grown extensively in all parts of the United States, and the fresh fruits are on the markets at all seasons. The uses of the tomato are several, and cultural practices vary widely. Hence, tomato production falls into several classes: table stock for shipment to distant markets; table stock for local markets; stock for canning and manufacture of catsup, paste, puree, and soup; seed production; and greenhouse production for winter markets in northern regions.

Taxonomy.—The tomato was assigned to the genus *Lycopersicum* by Philip Miller (1691–1771). The generic name signifies "wolf's peach," which indicates the low esteem in which the fruit was held. Some botanists place the tomato in the genus *Solanum;* but it differs from *Solanum* in its freedom from spines, in its pinnate or pinnatifid leaves, its mode of anther dehiscence, and in the hairiness of its seed.

Two species are recognized: *L. esculentum*, having hairy plants with a strong odor; and *L. pimpinellifolium* (*L. racemiforme* Lange), which is not hairy and has little odor. The latter is commonly called "currant tomato." Its plants are of weak, spreading habit, with small, thin leaves, and the flowers are arranged in two rows on a long raceme. The fruit is two-loculed and about $\frac{3}{8}$ inch in diameter. *L. esculentum* is a larger, more vigorous plant, and the fruit is larger and more variable than that of *L. pimpinellifolium*. Halstead (1905) found these species to cross readily. Several types of *L. esculentum* are classified by Bailey (1890) as botanical varieties, though all are supposed to have had a common origin. The wild type is thought to have been similar to the cherry variety. Bailey (1890) says "the effect of cultivation has been to increase the size of the fruit by interposition of new cells. Modern sorts have been developed . . . by modification of the flower and the production of an abnormal number of parts." Probably mutation has given rise to some of the present-day forms. The classification according to Bailey (1924) is as follows:

L. esculentum var. commune, (Var. *vulgare*, Bailey).—The large-fruited type, with "standard" foliage and spreading habit of growth.

L. esculentum var. validum.—The stems are thick, stout, of upright growth, very dark green, and have short, dense leaves. Dwarf tomatoes.

L. esculentum var. grandifolium.—The foliage is of the potato-leafed type, having entire margins. The plants are of spreading habit, and the

fruit is large and pluri-locular. Plants of this character sometimes occur in plantings of ordinary varieties.

L. esculentum var. cerasiforme.—The fruits are cherry-like, small, globular, and two-loculed. The plants are of standard type, though of slender growth and have small, light-green leaves.

L. esculentum var. pyriforme.—The fruits are pear-shaped, with a constriction at the stem end, and are small and two-loculed; plants are of standard type.

History.—The tomato is a native of tropical America. It was cultivated by the Indians from Mexico to Peru before the Spanish conquest. The cherry tomato has been found growing wild in Peru, the West Indies, the Canary Islands, and the Phillipines. Bancroft says it was eaten by the Mexican tribes, who called it *tomati*. In Peru, from which country the large-fruited forms were taken to Europe, it was called *tomate*. According to Sturtevant (1921), it was first mentioned in Europe in 1554 as *pomi d'oro*, a name which is shortened to *pomodoro* in modern Italian. Northern-European countries received it from Italy, the name "golden apple" being used first, then "love apple" and, finally, in 1695 Sloan referred to it as "tomato."

The tomato attained great favor as a vegetable in southern Europe soon after its introduction, but in northern Europe it was considered poisonous and was grown only as a novelty until about 1850. The first mention of its culture in the United States is by Thomas Jefferson in 1781. In 1802, tomatoes were brought to Salem, Massachusetts, by an Italian painter; and by 1835, they were being sold regularly on the Boston markets. Before this, they were used extensively by the French people at New Orleans. Thorburn, of New York, gives cultural directions for tomatoes in his 1817 seed catalogue.

The tomato first taken to Europe seems to have had a large, oblate, ribbed fruit, and this type was the one grown first in the United States. Large, round-fruited forms were described in 1700 by Tournefort, and non-ribbed forms were catalogued by Tilly, at Pisa, in 1723. Probably, modern varieties came more directly from the oblate, ribbed, many-celled type than from the cherry or other two-loculed forms. The cherry and the currant tomatoes are the only forms reported as growing wild. The tomato has, however, been under cultivation from a remote period and reached European and North American culture in a form probably quite different from any wild progenitor.

The development of modern American varieties began in 1870, when Col. J. E. Waring, of Newport, Rhode Island introduced the Trophy. During the next 25 years, many new and improved varities were introduced, A. W. Livingston of Columbus, Ohio, being a leader in this work. Since 1895, the important changes have been in the improvement of extra-early varieties and the breeding of disease-resistant strains.

Plant Characteristics

Roots.—The radicle of the germinating seed grows into a thick tap-root 2 feet or more in length and bearing several laterals. These develop horizontally for a distance of several feet. The smaller fibrous roots are borne on the tap-root and on the laterals. When tomato plants are transplanted, the tap-root is destroyed, and the roots system consists only of horizontal laterals near the surface of the soil. Plants grown from seed planted directly in the field have a well-developed tap-root and a deep root system. Kroemer (1918) found that 3 weeks after planting, the taproot was 75 centimeters long and that after 5 weeks, it was 123 centimeters long.

Fig. 47.—Root systems of tomato plants. A. Transplanted. B. From field sowing.

In the presence of moisture, adventitious roots develop from any portion of the stem. Primordia of these adventitious roots are often seen on the lower portion of the main stem and on the lower sides of decumbent lateral branches.

Stems.—The main axis is erect until a height of 1 to 2 feet is attained, when it becomes decumbent. The stems become woody with age. Lateral branches arise from each leaf axil, though not all of them develop, unless the growing point of the stem is removed. These produce secondary laterals. The cortex bears numerous hairs, and trichomes capped with an oil gland. The latter are ruptured in handling and liberate the characteristic tomato odor and stain.

Cuttings of tomato stems will root in water or in moist sand. Miss Reid (1924) showed that the composition of tomato stems and of the medium in which they were placed influenced regeneration. In a solution containing nitrates, cuttings high in carbohydrates made vigorous growth of both roots and shoots; cuttings low in carbohydrates (and high in N) produced neither shoots nor roots. In a solution without nitrates, carbohydrate-high cuttings made no shoots but had abundant roots; cuttings low in carbohydrates but high in N produced considerable shoots but no roots.

Leaves.—The leaves are alternate and are pinnately compound in most varieties. In the Potato-leaf variety, the divisions of the leaf are

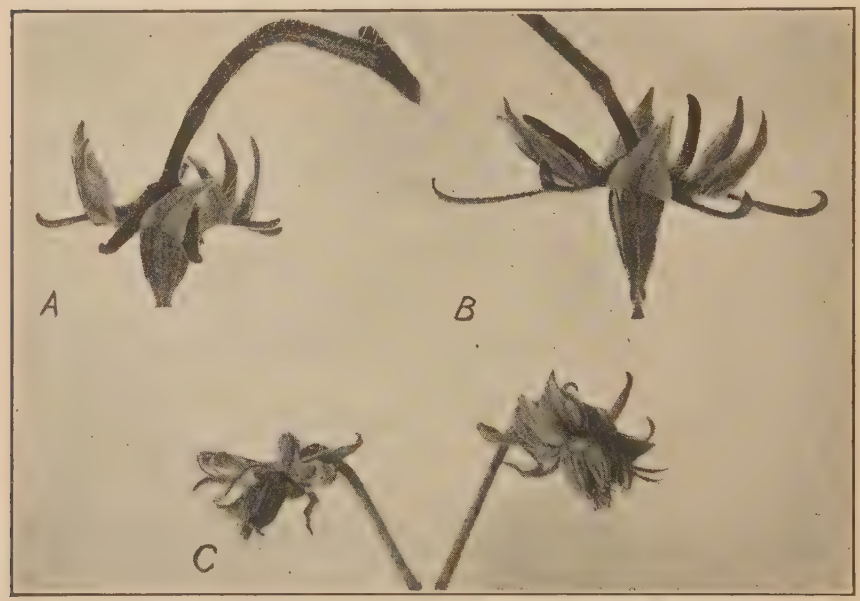

FIG. 48.—Types of tomato flowers. A. Short styled, the stigma is recessed within the staminal cone. B. Long styled, the stigma projects beyond the stamen. C. Fasciated pistils.

fewer, and the margins are entire. The Cherry tomato bears rather distinctive tripinnate leaves. On the leaves are found numerous glandular hairs like those on the stems.

Flowers.—The flowers are borne in dichotomously branched cymose inflorescences, except in the Currant tomato, where they are in two-ranked racemes. The number of flowers in an inflorescence varies from 4 to 8 in the large-fruited varieties to over 50 in some small-fruited forms. The former are termed "simple" by the geneticists and occur at every third node; the latter are called compound and occur at every sixth node. The inflorescence is terminal on the main axis. After formation of the

inflorescence, an axillary shoot arises from the adjacent node; it develops three or six nodes and terminates again in an inflorescence. This may be repeated an indefinite number of times, until the stem becomes several feet long, bearing fruit clusters throughout its length. The peduncle is often adnate, being united with the main axis for a short distance. This arrangement makes the inflorescence appear to arise from the internode.

The flowers of an inflorescence open at intervals over a period of several days, those more basally situated developing first and producing also the largest fruits. In greenhouse culture, thinning is practiced by removing the flowers on the distal end of the cyme. The calyx is five- to ten-parted and persists until the fruit is mature, with little increase in size. The corolla is a short tube, expanding at the top into five or more lobes, sulphur-yellow in color; the withered corolla may persist at the stylar end of the fruit until maturity. There are five or more stamens attached to the corolla tube; their filaments are very short, and the anthers are partly united to form a cone around the pistil. Dehiscence begins about 2 days after the corolla first opens.

Pollination.—The flowers are usually self-fertilized. Their pendent position favors self-pollination. The pistil elongates rapidly during the maturation of the flower, pushing the stigma through the staminal cone, which insures selfing, if pollen is being shed. In some varieties, however, and probably in some flowers of all varieties, the style elongates before the anthers dehisce, thus exposing the stigma to foreign pollen.

Fink (1898) found that the stigmas were receptive 1 to 2 days before anther dehiscence; hence, in making crosses, emasculation and pollination can be performed at the same time. The stigmas remain receptive for 4 to 8 days. Dehiscence is by a longitudinal split on the inner side of the anther, at the top. Pollen grains removed from the anthers before dehiscence were not able, according to Fink, to cause fertilization. Mature pollen may remain viable for as long as 2 weeks.

In nature, some cross-pollination may occur. Jones (1916) found evidence of 2 to 4 per cent crossing in the Dwarf Champion variety, when interplanted with Stone. White (1918) noted that in some varieties the style projected beyond the staminal cone at the time dehiscence occurred, while other varieties had shorter styles, the stigma not projecting beyond the anthers. Varieties of the latter type set fruit freely in the greenhouse without hand-pollination, while the former required it. Lesley (1924) found that in Magnus, a long-styled variety, there was about 5 per cent cross-pollination, while with Dwarf Champion, a short-styled variety, there was only 0.58 per cent crossing.

Fink (1890) concluded that wind-pollination seldom or never occurs in tomatoes. According to his observations, the only insect which visited the flowers was the bumblebee, which feeds on the pollen. As pollen grains are carried on the bumblebee's body it is probable

that most of the cross-pollination of tomatoes is due to this insect's visitations.

Fink found that tomatoes could not be fertilized by *Solanum nigrum*, *Datura stramonium*, or *Physalis pubescens*. Parthenocarpy is not unusual in the tomato, but parthenocarpic fruits are usually small. Hartley (1902) seemed to find a stimulus to the setting of parthenocarpic fruits, when the stigma was dusted with magnesium sulfate instead of pollen. Sandsten (1905) observed plants growing in the greenhouse with abortive stamens and fasciated pistils, which produced fairly large, seedless fruits, the ovules being completely aborted. Cuttings of these plants, propagated in the field, also produced seedless fruits.

Abscission Zone.—There is an abscission zone in the pedicel. It consists of a slight swelling, with a deep, narrow groove extending halfway through the cortex, and four to six layers of small, rounded cells, extending across the pith of the pedicel. The groove originates by the failure of the cortical cells to develop in that particular region; it has no essential connection with abscission. The abscission layer is formed, according to Kendall (1918), when the buds are only 1 to 2 millimeters long; later events determine whether it will develop and cause the abscission of the flower or the young fruit. Mechanical injury to the ovary, lack of pollination or fertilization, and exposure to small amounts of poisonous gases cause floral abscission, but Kendall thinks that physiological conditions within the plant, as influenced by soil moisture and fertility, are the chief causes in the field. He showed that 2 or 3 days after pollination, mechanical tissue develops in the pedicel, so that even if the separation layer developed after that time, the young fruit would not fall. When abscission takes place, the middle lamella of the small pith and cortical cells forming the abscission layer is dissolved by enzymatic action, and the cells separate.

Another abscission zone develops between the calyx and the fruit, as the latter nears maturation. In it, corky cells develop, and when the fruit is ripe, separation along this line is easily forced.

Fruit Setting.—The floral primordia are laid down in proximity to the growing point of the shoot, but by the time of flowering, considerable elongation of the stem has occurred. Flowering is indeterminate, the various clusters opening in succession from the base toward the tip throughout the growing season.

Flower-bud formation occurs under a very wide range of conditions, but the setting of fruit is limited to a much narrower range. Abscission may occur before, during, or shortly after anthesis, resulting in the dropping of the flowers. Kraus and Kraybill (1918) showed the relation of internal conditions, as affected by some environmental factors, to fruit setting in tomato. They showed that when N is very deficient in the soil, the plant is stunted, has a high starch and low N content, and does

not set fruits. When N is fairly abundant, the plants grow well, have a moderate content of both starch and N, and set fruit freely. When N is very abundant, the plants grow rapidly, have low starch and high N content, and do not set fruit. This illustrates the effect of a single limiting factor on the activities of the plant. Other limiting factors, however, may have the same effect—variation in moisture or in any of the essential mineral elements may theoretically cause the same range of conditions. Kraybill and Smith (1924) report that by modifying the amount of available P, plants with varying degrees of vegetation and reproduction were obtained.

Setting of fruit in the tomato is associated with moderate vegetative growth. If conditions are such that vegetative growth is rapid, the carbohydrates are used in new tissue formation, the concentration of carbohydrates in the plant consequently remains low, and, while blossoms are produced abundantly, they fall without setting fruit. Under extreme conditions of high N with low carbohydrate, such as may occur when light is restricted, even bud formation may not take place. If, on the other hand, conditions allow little vegetative growth, the carbohydrates produced by the leaves exceed the needs for new tissue formation. Then the products of photosynthesis accumulate in the plant, a high concentration of carbohydrates results, and, again, the blossoms fall without setting fruit. With intermediate conditions, fruit-bud formation and fruit setting take place freely. A convenient view of the situation is that fruit setting depends on a more or less definite concentration of carbohydrates in the plant, a concentration which is determined in part by the rate of vegetative growth and in part by the conditions, such as light, affecting carbohydrate manufacture. Work (1924) shows that fruit setting in tomato is not dependent on any definite mathematical ratio of carbohydrate to N content. The carbohydrate content may simply be a resultant of the plant's metabolic activities, on which fruit setting depends. Under field conditions, plants may pass through the whole series of conditions, from one extreme to the other, within a single growing season. Excessive vegetative growth and failure to set fruit often result from liberal moisture or nutrient supply or both. Tomatoes should not be given large amounts of nitrogenous manures, except where N is very deficient in the soil, and the moisture supply should be carefully regulated during the time when fruit setting is most important.

Nightingale (1922) found that the length of daily illumination, in connection with varying nitrate supply, can markedly affect the reproductive activity of tomatoes. Plants grown with a 7-hour day, plus nitrate, were extremely vegetative but set no fruits. Plants receiving the same nutrients, but with a 14-hour day, set fruit abundantly. With the short day and no nitrate, there were numerous flowers but no fruit; with the long day and no nitrate, there were neither flowers nor fruit. Night-

ingale's results led him to conclude that the amount of nitrate present as such in the plant does not materially affect the type of growth. He thinks that the proportion of carbohydrates to insoluble N and not the total amounts of these substances determines the type of growth made by plants.

Floral abscission may occur even when nutrient conditions are suitable for fruit setting. Radspinner (1922), noted that tomato flowers dropped during hot dry periods in Oklahoma. This dropping was most severe when soil moisture was deficient or the temperature was high, but a more direct relation existed between the relative humidity of the air and the dropping of the flowers. He concluded that conditions conducive to rapid transpiration resulted in a water deficit in the plant, which caused the development of the abscission zone.

Failure to set fruit is sometimes attributable to injury by thrips. According to Watson (1914), when thrips are very numerous, the pistil is injured. Tests in California show that two or three thrips per flower do no damage but may aid in self-pollination of the flowers.

Fruit.—The tomato fruit is a fleshy berry. Its flesh consists of the outer wall (pericarp), the radial walls, or interlocular septae, the placenta, and the core. The seed is embedded in a jelly-like mass of thin-walled parenchyma tissue, which fills the locular cavity when the fruit is mature. This tissue is absent during the early stages of fruit development; it is formed by outgrowths of placenta and finally engulfs the seed. It touches but does not unite with the outer and radial walls; it is not attached to the seeds. The juice of this matrix is more acid than the flesh.

The stem end of the fruit is usually more or less depressed and is known as the "cavity." The apical end of the fruit bears the remains of the style and, in some cases, a rather large, corky area, the stylar scar; in some varieties, a depression known as the "basin," occurs at the apical end; other varieties have protruding secondary ovaries, or navels.

The shape of the fruit is a varietal characteristic; it may be round, oblate, elongated, or constricted. Size varies according to the variety, from 7 to 8 grams in Red Cherry, to 500 grams in San Jose Canner. Cultural conditions and the position on the inflorescence also influence fruit size. The number of locules varies from two in such varieties as Red Pear and Cherry to 18 or 20 in some of the largest-fruited varieties. The latter generally have fasciated pistils, a large number of locules, and extreme roughness or irregularity of form in the mature fruit.

The skin of the tomato fruit consists of a single cell layer—the epidermis—and three or four cell layers of collenchyma, the cells of which are smaller and more flattened than the underlying parenchyma cells. The outer wall of the epidermal cells consists of a heavy, cutinized layer, which extends into the radial walls of these cells. All varieties except the Currant tomato, bear glandular hairs on the epidermal cells

in young fruit, but they drop off before maturity, except in the Peach variety, which is pubescent until ripe. No other consistent differences in the fruit skin were observed by Groth (1910), who studied many varieties.

The time between fruit setting and maturity, in the Globe variety, is given by Sando (1920) as 49 days on a summer crop at Arlington, Virginia, and 56 days on a winter crop at Peters, Florida. Sando found the growth period to be approximately the same for both large and small fruits. On the other hand, Miss Krassowska (1926) reports that in Poland, a period varying from 54 to 65 days elapsed between fruit setting and ripening, and her tables show that the smaller fruit ripened in a shorter time than did the large fruit. Early-set fruit required a longer period to ripen than that set later.

The growth of the tomato fruit is peculiar, in that increase of size takes place without an increase in per cent of dry matter. Sando, in Florida, reports a slight but regular increase in moisture content throughout the growth period, and Rosa (1925), in California, found that, in

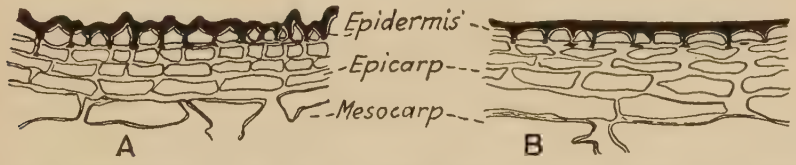

FIG. 49.—Cross section of the skin of tomato fruit. A. Peach variety. B. Smooth variety. (*After Groth.*)

general, the water content increased in fruit passing from green-mature to ripe condition. This type of growth is attributed by MacDougal (1919) to the extraordinarily high imbibition capacity of tomato fruits, due to their content of amino acids, salts, and sugar. Rosenbaum and Sando (1920) state that there are no stomata or other natural openings in the epidermis of either young or old fruit; they find that the cuticle of the epidermis increases in thickness and toughness as the fruit becomes older. In ripening, then, the fruit becomes more resistant to puncture and to invasion by fungi.

Fruit Color.—Ripe tomato fruits owe their color to certain pigments. The red pigment is lycopersicin and occurs as needle-like crystals in the cells of the flesh. It is a hydrocarbon with the empirical formula $(C_5H_7)_8$. Another pigment, carotin, which is isomeric with lycopersicin, also occurs in the flesh as yellow granules. According to Miss Howard (1925), the carotin granules are contained in chromoplasts, which result from the degeneration of chloroplasts; lycopersicin crystals occur free in the cell sap, without apparent connection with plastids or with chlorophyll.

The presence and distribution of pigments varies in different varieties. In lemon-yellow fruit, carotin occurs in the pericarp, but the epidermis is

colorless; in orange-colored fruit, carotin occurs both in pericarp and epidermis; in pink fruit, lycopersicin occurs in the pericarp, but the epidermis is colorless; in red fruit, lycopersicin occurs in the pericarp and carotin in the epidermis and probably in the pericarp as well. Albino, or white, fruit lacks all pigments.

Seed.—The numerous seeds are borne on the axile placentae. They are covered with fuzzy hairs, which distinguish them from other solanaceous seeds. According to Souèges (1907), the hairs originate as radial cellulose thickenings in the cells of the outer layer of the seed coat. At maturity, the outer wall of these cells disintegrates, leaving the thickenings free as hairs. The seed is viable before the fruit is fully ripe, but continues to increase in weight during fruit ripening. The reserve material in the seed is chiefly protein and oil globules. Goff (1891) found that seed from immature fruits gave plants with a higher ratio of fruit to vegetative growth, including stems, leaves, and roots, than did seed from ripe fruits. The immature seed also gave ripe fruit 10 days to 4 weeks earlier. These results were attributed to the limitation of

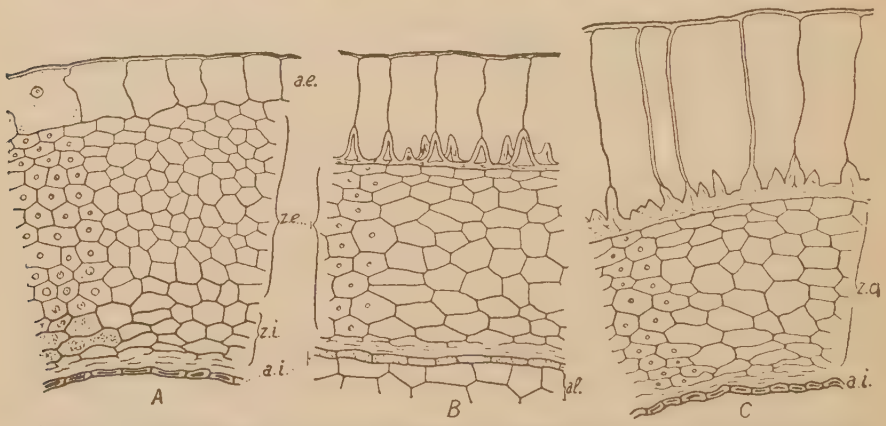

FIG. 50.—Three stages in the development of the seed coat in tomato, showing the separation of the single integument into 3 distinct layers. In ripening, the outer wall of the external layer is dissolved, leaving the tangential walls as "hairs." (*After Souèges.*)

vegetative growth by the weakness of the plants from immature seed, which, under certain conditions, might result in greater fruitfulness and earlier maturity. There was no cumulative effect when propagation by immature seeds was continued for 3 years.

The size of the seed does not seem to affect materially the yield of fruit. Thus, Jordan (1901) selected two lots of 50 seed, weighing 0.176 and 0.071 grams respectively. These gave about the same total yield; plants from small seed, however, ripened their fruit somewhat earlier. Brown (1924) found that commercially harvested seeds from diseased plants were slightly smaller than seed from large fruits, while seeds from

small fruits were much smaller than either. The percentage of germination was much lower in all the lots of light seed; there were no significant differences, however, in yield from large and small seed. Rosa (1926*B*) found that the average weight of the seed decreased toward the latter part of the harvest season, with no difference in productivity of seed haversted at different periods and of different weights.

Climatic Relationships

Temperature.—The tomato is a warm-season plant. Its tissues are frozen and killed at temperatures slightly below 0°C. It cannot be hardened to withstand freezing, though hardening treatments may lower the freezing point somewhat. Frost injury to young plants of the early crop is avoided mainly by regulating the transplanting date according to the locality.

In central and northern sections, the plants are usually killed by frost before a full crop of fruit is produced. There, the yield of ripe fruit increases with the earliness of the planting date and with the earliness of the variety. Clayton (1923*A*) found that tomato plants under greenhouse conditions grew most rapidly at soil temperatures ranging from 24 to 31°C. At 33°C., the plants grew slowly, and at 35°C., they lived but did not increase in size. Pritchard and Porte (1924) show that the states having the greatest average yields have a mean summer temperature of 22 to 24°C.

The freezing point of the fruit is a little lower than that of the foliage, varying, according to Harvey and Wright (1922), from −1.23 to −.74°C. in different varieties. Green fruits have a freezing point slightly higher than ripe fruits. The latter may be undercooled to −5.6°C., without injury, providing ice formation does not take place. Under field conditions, free moisture collects in the stem-end depression and freezes, thus inoculating the fruit with ice crystals and preventing undercooling.

Moisture.—Soil moisture is important in connection with various pathological conditions, for instance, blossom end rot of the fruit, usually associated with deficient moisture. Abundant soil moisture, with abundance of plant nutrients, may result in rapid vegetative growth, without fruit setting. It is generally believed that tomato fruits grown on moist soils or during periods of wet weather are low in content of solids, soft, and lacking in flavor. Bigelow (1916), however, at Washington, District of Columbia, found no relation between rainfall and per cent of solids in the juice. He noted a tendency for the soluble solids to decrease during the picking season, though the rainfall was much greater in the early part of the season. He suggests that wet weather may so alter the structure of the fruit that it does not hold its juice so firmly, hence may seem to be more watery. In California, the content of solids in

fruit grown under dry-farming conditions is slightly lower than that of fruit grown under irrigation (Rosa, 1926*B*).

MacDougal (1919) studied the daily accretion in size of tomato fruits, in connection with temperature and water relations. As the temperature of the fruit (attached to the plant) rose from 12 to 14°C., to 26 to 28°C., the weight increased up to a point where the increased temperature caused a water loss by transpiration, which overbalanced the gain by hydration. The midday shrinkage could not be prevented by watering the plants abundantly. This shows that a water deficit may exist in the fruit because of high transpiration, regardless of the moisture content of the soil.

Light.—Miss Pfeiffer (1926) exposed tomato plants to daily illumination periods ranging from 5 to 24 hours. With 5 or 7 hours' light, growth was feeble. With 17 hours, or more, of light, the plants were injured and finally killed. The long light period was found to interfere with protein synthesis; it favors carbohydrate accumulation but interferes with storage of starch and with the utilization of carbohydrates in tissue extension. Plants with 12 hours of light daily made the greatest growth and, at the same time, had the most reserve protein and carbohydrate. Popp (1926) showed that the growth and fruiting of tomato were little affected by exclusion of short-wave-length light. When the wave lengths below 472 $\mu\mu$ were excluded, however, the plants grew very tall and spindling, as they usually do when grown in semi-shade.

Cultural Methods

Planting Date.—Usually, the crop for local market and for shipment is planted earlier than the canning crop. From 8 to 10 weeks should be allowed between dates of sowing seed and of transplanting to the field. From 8 to 14 weeks elapse between the date of field setting and the beginning of harvest. Kotowski (1926) found that tomato seed does not germinate at 8°C. At 11°C., from 22 to 33 days are required for seedlings to appear. The speed of germination increases with the temperature; at 30°C., 4 to 8 days are required.

Methods of Plant Growing

For the sake of economy of seed, of earliness, and of convenience in growing the crop, the plants are usually grown in beds, with one or more intermediate transplantings, before being finally set in the field. Methods of plant growing differ.

Hotbed-coldframe method.—This is generally best for early-market crops and for shipping and canning crops in the North. Greenhouses are also much used for plant growing. Seed is planted in rows, or broadcast in a bed which is kept warm and moist until the plants are up, after which

time, it should be well ventilated and sparingly watered. When the seedlings show their first true leaves, they are transplanted to flats, small pots, or the coldframe. When the plants are 10 inches high, the terminal bud may be pinched out of each plant. This prevents the latter from growing too tall, favors thickening of the stem, and forces shoots in the axils of the leaves. Thus, the framework for a large, bushy plant is well started before the plants are set in the field.

For a week or 10 days before transplanting to the field, the beds should be left open day and night and only enough water applied to keep the plants from prolonged wilting. This hardens them, so that they will stand transplanting readily. The xeromorphic characteristics, developed during the hardening process, such as thickened cuticle, smaller cells, increased sap concentration and reduced leaf area as compared to non-hardened plants, protect the plants from excessive desiccation when transplanted to the field (Rosa, 1921). Loomis (1925) suggests that the greatly increased carbohydrate content, which results from the hardening process, is favorable to prompt regeneration of the root system.

Cold-frame Method.—This is used when plants are started in cool weather but not so early as in the hotbed method. The seed is sown thinly, in rows 4 to 6 inches apart. The plants are thinned to about three to the inch. This method may be used to produce large numbers of plants cheaply, but by the same means, it is difficult to grow large stocky plants with well-developed roots.

Open-bed Method.—This method is the cheapest way to grow plants. It is not adapted to sections having short growing seasons nor to early crop production. The seed is drilled in garden beds, when danger of frost is over. Tomato plants in the South are grown in the open on a large scale in spring. They are pulled, packed with wet moss about the roots, and shipped for field planting to points farther north.

Seeding Directly in the Field.—In sections having a long growing season, tomatoes may be planted directly in the field. This method is wasteful of seed and involves considerable labor in thinning, and the crop is later in maturing than when it has been transplanted from a hotbed. The method is of value, however, where a large number of plants per acre is wanted; the deep tap-root formed by field-sown plants may also be of advantage. In the Imperial Valley of California, in Washington, and in southern Texas, this method is followed.

Transplanting.—The preservation of a large amount of the original root system is probably unimportant. If the plants are well hardened to prevent immediate desiccation, they form a new absorbing system very quickly. Experiments by Shapovalov (1925) showed that when all the fibrous roots were stripped off, the plants grew as well as plants whose fibrous roots were preserved in transplanting. Transplanting, however, always retards plant growth and is to be regarded as a necessary evil in

growing tomatoes in regions having short seasons. Lloyd (1910) showed that several transplantings in greenhouse or hotbed before transplanting to the field also retarded growth considerably.

In some districts, various kinds of plant protectors are used to advantage in the early part of the season. In the Imperial Valley, tomatoes are planted on the south side of the ridges and sheltered by palm leaves or by sticks interwoven with newspapers. Hibbard (1925) reports the successful use of glassine-paper protectors in Michigan, the minimum night temperature being 0.61 to 1.5°C. higher under these covers.

Irrigation.—In the Middle West and East, tomatoes are grown without irrigation, though experiments indicate that yields can be very materially increased by irrigation in dry seasons. Thus, Rosa (1923), in Missouri reports increases in yield of 56, 76, and 35 per cent from irrigation in 3 successive years; and Stuckey (1915), in Georgia, obtained even larger increases. In the West, in some localities, tomatoes are grown without irrigation and without rainfall during the growing season, though irrigation is generally practiced. The number and frequency of irrigations are determined by local conditions. Heavy or frequent irrigations may favor excessive vegetative growth and abscission of most of the early flowers.

Covering the surface between the plants with a straw mulch, which conserves the moisture in the surface soil, has been reported by Stuckey (1915) and Rosa (1923) to increase the yield almost as much as irrigation increases it, although the ripening of the fruit is retarded somewhat, because of the lower soil temperature under the mulch.

Staking and Pruning.—The merits of pruning tomato plants to one or more stems and of training the stems upright on stakes, as compared to allowing the plants to grow naturally, have been extensively tested. The former method is necessary under greenhouse conditions and is used on the early field crop. Advantages of the staking and pruning method are as follows: The plants and fruits are kept from contact with the soil and so are less subject to decay of fruit and to foliage diseases; the number of plants per acre is increased through closer planting; the size of the individual fruits, the proportion of the crop graded as fancy, and the yield of early fruit may be increased. Pruning increases the percentage of fruit set on the first flower cluster, probably because of the increased carbohydrate content of the plant through limitation of its vegetative growth by pruning.

Disadvantages of staking and pruning are: the cost of labor and materials; decreased total yield per plant; and increased susceptibility to diseases connected with water deficit in the plant. Thus, Stuckey (1915) found blossom end rot much more prevalent in staked plants. Pruned tomato plants have a less extensive root system than have non-pruned according to Thompson, (1927).

Olney (1918) reports average yields in Kentucky for five varieties not staked or pruned and set at the rate of 1,815 plants per acre, as 7.4 pounds per plant or 13,414 pounds per acre; while the same varieties, staked, pruned, and set at the rate of 5,445 plants per acre, gave 4.75 and 27,494 pounds, respectively. Rosa (1922) compared plants set 2 by 3 feet apart, pruned, and staked to plants set 3 by 3 feet apart and not pruned or staked. The latter produced double the total yield per acre but only 19 per cent of early fruit, compared to 31 per cent on the staked, pruned plants. The amount of early fruit to the acre was greater, however, on the non-pruned, non-staked plants. Lloyd (1901) found that topping staked plants after three clusters of fruit had set reduced the yield of early fruit slightly and that of late fruit very markedly.

Manures.—The effect of manures upon yield and earliness of tomatoes varies according to soil and perhaps other factors. Lloyd (1910), in Illinois, and Rosa (1922), in Missouri, obtained increased yields with more early fruit from chemical manures, particularly those high in P, whereas stable manure increased total yields without increasing early production. Hepler (1924), in New Hampshire, obtained an increase of 346 per cent in yield of ripe fruit, from the application of 1,000 pounds per acre of acid phosphate; in the same experiment, a retarding effect on production of early fruit was exerted by potassium chloride. The latter may not be taken as a generally true relationship, however, for experiments in other states have shown that K is either without effect or increases the yield. The effect of chemical manures on earliness is probably due to the more rapid development of the vegetative parts of the plant in the early stages, when an element deficient in the soil is supplied, than to any specific stimulus to fruit development and ripening. Hepler and Kraybill (1925) also observed a higher per cent of fruit setting on the early clusters, where P was applied. In the Delaware experiments (McCue and Pelton, 1913), where P did not increase the total yield materially, it did not increase the proportion of early fruit, either. But potassium chloride greatly increased total yield and likewise increased the proportion of early-ripened fruit, in these experiments.

The use of nitrogenous materials is generally considered undesirable for tomatoes, especially from the standpoint of earliness. Delayed fruit setting and late maturing of the fruit are sometimes observed when nitrate of soda is applied. Stable manure has a similar effect. On the other hand, in some soils, N is the limiting factor. Voorhees (1889), in New Jersey, reports the greatest increase in yield from nitrate of soda.

Tomatoes, according to Hartwell (1914), are not benefited by application of lime when grown on a rather acid soil. Work (1926), in New York, observed a decrease in yield, where 2 tons per acre of limestone was applied annually for 3 years. Experiments in New Jersey, West Virginia, Texas, and Missouri also indicate no benefit to tomatoes from

lime, but in Ohio, Magruder (1924) reports that lime increased the yield when used in connection with stable manure or with a cover crop of cowpeas. Lime may be of indirect value through its influence on green manuring crops grown in the rotation. Magruder suggests that the occasional depression in yield of tomatoes treated with lime is due to its rendering P partially unavailable to the plant. This fact may explain why applications of raw rock phosphate (tri-calcium phosphate) are of little benefit to tomatoes even where P is the limiting element.

Sulphur may be important in the nutrition of the tomato. Marsh (1922) reports the amount of S in tomato tissue to be two and one half to four times as great as the amount of P; the amount of S increased, from the growing point toward the base, its distribution showing an inverse relation to P. Sulphur content increased also with the age of the plant, and Marsh suggests that it may serve the function of releasing P from the older portions of the plant, for reutilization in the growing regions. The amounts of P and of S in the tissues are increased when the plants are fertilized with acid phosphate; the beneficial effect of acid phosphate on growth and yield may be in part due to the S in this material. Phosphorus has been considered especially important in the formation of seeds; MacGillivary (1925), however, shows that the total amount of P is much greater in the pericarp than in the seeds. The per cent of P, high in young fruits, declines throughout the period of fruit development, but the total amount in the whole fruits increases until the fruit is nearly mature.

Harvesting

In picking, tomatoes are separated from the stem by a quick twist, leaving the calyx attached to the plant. Green-mature fruit should show a brownish ring under the calyx. If this area is greenish white, the fruit is immature. Inspection of the abscission zone aids in eliminating immature fruits at the packing house. Pickers may be guided by the change from whitish, or light green to yellowish green at the stylar end of the fruit, as the latter approaches the mature condition.

The degree of ripeness at which the fruit is harvested depends upon the method of marketing. For canning and for manufacture of tomato products, it is fully ripened on the plant. For local markets, where it will reach the consumer within 2 or 3 days, it is harvested at the pink stage. For shipment to distant markets, green-mature fruit is generally used because of its firmness. The following are the terms and definitions of maturity of tomato fruit:

Immature.—Before the seed-cavities have begun to develop a jelly-like consistency and before the seeds are fully developed.

Mature-green.—The fruit is full grown but has not begun to turn color. The seed cavities are filled with a jelly-like material.

Turning.—The fruit is green at the stem end and over the shoulders but about one-fourth of the surface shows color, at the blossom end.

Pink.—About three-fourths of the surface is colored.

Hard Ripe.—Nearly all of the surface is pink or red, and the fruit is firm.

Overripe.—The fruit is fully colored and soft.

Color is the chief external sign of maturity. The main difficulty is in picking green-mature fruit. Size is not a guide, for the mature fruits vary greatly in size, according to their position on the plant and other factors. Fruits picked immature develop color after 2 or 3 weeks but are of poor flavor. They are unfit for food, and care is necessary to avoid picking and shipping them. Fruits picked in the green-mature stage, on the other hand, attain a normal color and, if ripened under favorable conditions, will be nearly equal in quality to those ripened on the plant. This condition, however, is often not realized in practice, due partly to the shipment of many immature fruits and partly to the conditions under which the shipments are made.

Ripening Process.—The red or pink color of ripe fruit is due to the pigment, lycopersicin; and the yellow, to carotin. Both pigments develop in fruit either on or off the plant, in light or in darkness, but lycopersicin formation is inhibited by either low or high temperatures. Duggar (1913) found that green tomatoes stored at 35°C. were ripe in 6 days but yellowish in color, due to the failure of lycopersicin to develop at that high temperature; at 20 to 25°C. and 12 to 26°C. normal red developed. The yellowish fruit, ripened at 35°C., turned red when transferred to 22°C. Even at 30°C., formation of red color was somewhat inhibited. Lycopersicin formation was found to be irreversible; red tomatoes were not decolorized at high temperatures; hence, tomatoes ripen normally in the field with temperatures above 35°C. part of the time. The failure to redden at high temperature is probably due to lack of O_2 in the tissues, the limited supply being used up in respiratory activity, which is greatly accelerated at high temperatures. Rosa (1926*A*) found that green-mature tomatoes, stored at 4 and 8°C., developed no red pigment within 20 days, though the yellow pigment developed slowly; at 12°C., the red pigment developed very slowly.

That oxygen is essential for the ripening of tomatoes was also shown by Duggar. Tomatoes stored in other gases did not redden, though in N and in H some yellow appeared after 10 days. Sando (1920) found that tomatoes ripened in chambers with a deficiency of oxygen or when wrapped in paper developed an abnormally high acidity, were somewhat low in sugars, and had a poor flavor.

Chemical changes in the ripening of fruit, both on and off the plant, are important. The flavor is determined largely by the amount and kind of sugars and the acidity. Sando found that the total acidity

increases steadily until the green-mature stage is reached; it then decreases during ripening. Sugar content increases steadily from the time the fruit is formed until it is fully ripe. The ratio of sugar to total acid increases during ripening. The acid flavor, however, depends more on the H-ion concentration of the juice than it does on the total (titratable) acidity. Rosa (1925) found that the P_H of the juice varied only within narrow limits as the fruit passes from the green to the ripe condition, being highest in turning fruit and lowest in ripe fruit. Both Sando and Rosa found that acid-hydrolyzable carbohydrates, including starch, largely disappear during ripening. The sugars are mostly free reducing with very small amounts of sucrose, pentose, pentosans, or other carbohydrate. Briosi and Gigli (1889) claim that 90 per cent of the sugar is levulose. The per cent of total solids decreases during ripening, but the amount of soluble solids increases markedly. Table 51 summarizes the important changes during ripening, in the Stone variety, at Davis, Calif.

TABLE 51.—CHEMICAL CHANGES OF TOMATO FRUIT DURING RIPENING ON PLANT, PER CENT OF FRESH WEIGHT
(*Rosa*, 1925)

Stage of maturity	P_H of juice	Total acid (as citric)	Total sugar	Starch	Total nitrogen	Soluble N[1]	Total solids
Green-mature	4.3	0.853	1.92	0.435	0.186	54.3	5.94
Turning	4.1	0.943	2.31	0.206	0.186	54.1	5.99
Pink	4.2	0.910	2.28	0.118	0.191	63.0	5.63
Ripe	4.5	0.606	2.63	0.075	0.203	65.8	5.51

[1] Per cent of total nitrogen.

Artificial Ripening.—Tomatoes are generally shipped in the green-mature condition. Upon arrival at their destination, a few fruits are colored sufficiently to sell; the others are placed in ripening rooms at 25 to 30°C. The rooms are kept moist to prevent shriveling. At intervals of 2 or 3 days, fruits showing sufficient color are removed. From five to ten sortings are required. Some of the artificially ripened tomatoes are of inferior flavor. Sando showed that poor quality is due partly to immaturity of the fruit and partly to the practice of wrapping the fruit in paper, which excludes O_2 and so interferes with the ripening process.

In spite of their high acidity, Sando reports that the wrapped fruits were insipid in flavor. Wrapping seems to be undesirable and is unnecessary, because generally the fruit is repacked before entering retail trade. Because of the difficulty of picking green tomatoes which are mature enough to be of good quality when ripened, Sando suggested the ship-

TABLE 52.—EFFECT OF OXYGEN SUPPLY UPON ARTIFICIALLY RIPENED FRUIT
(*Sando*, 1920)

Conditions of ripening	Acid, per cent	Sugar, per cent	Ratio, sugar to acid
In box without ventilation	1.104	2.325	2.11
Wrapped in paper	0.850	2.462	3.01
Unwrapped	0.475	2.631	5.54
Ripened on the plant	0.420	2.667	6.34

ment of "turning" fruit. He found that tomatoes picked on the turn could be kept for 15 days at 10 to 13°C. and an additional 5 days at 24°C. Turning tomatoes ripened in storage developed about the same composition and flavor as those ripened on the plant.

Chemical changes during artificial ripening are of the same type as those during ripening on the plant. Total acid decreases, and starch disappears. Sando found that for the Globe variety, in Florida, fruit artificially ripened contained nearly as much sugar as that ripened on the plant. Rosa, in California, for Earliana, Stone, and Globe varieties, found that artificially ripened fruit has only slightly more sugar than green fruit and considerably less than fruit ripened on the plant; with the Globe variety, however, the sugar content of artificially ripened more

TABLE 53.—COMPOSITION OF ARTIFICIALLY RIPENED TOMATOES PICKED IN GREEN-MATURE STAGE
(*Rosa*, 1925 *and* 1926)

Condition of fruit	Total acid (as citric)	Total sugar	Starch	Total solids	Soluble solids[1]
Earliana variety:					
Green-mature	.....	2.14	0.140	5.39	
Ripened in air	0.644	1.90	.....	5.46	
Ripened in ethylene	0.541	2.14	0.035	5.02	
Ripened on plant	0.460	2.75	0.034	5.33	
Globe variety:					
Green-mature	0.779	2.38	0.410	6.10	71.5
Ripened in air	0.635	2.57	0.096	5.86	
Ripened in ethylene	0.677	2.78	0.119	5.61	79.4
Ripened on plant	0.586	2.88	0.131	5.88	84.0
Stone variety:					
Green-mature	0.981	2.47	0.629	7.29	64.6
Ripened in air	0.666	2.27	0.098	6.22	77.4
Ripened in propylene	0.657	2.53	0.098	6.49	77.2
Ripened on plant	0.706	3.07	0.052	6.72	81.5

[1] As per cent of the total solids.

nearly approached that of plant-ripened fruit than did Earliana and Stone. In artificial ripening, some gain in sugar is to be expected from the hydrolysis of starch, but this may be overbalanced through destruction of sugar by respiration. Table 53 shows the changes in the fruit during artificial ripening.

Green-mature tomatoes ripened in air at 20 to 22°C. require from 6 to 20 days to develop sufficient color to be marketable; this long ripening period results in shrinkage, loss of flavor, and loss by decay. Rosa (1925 and 1926) found that ripening was accelerated by adding to the air of the ripening room small amounts of ethylene or propylene gas, the latter being somewhat more effective. Concentrations of 1:400 to 1:5,000 were about equally effective; the charge of gas is renewed daily, because of losses by diffusion. These gases cause the red pigment to develop rapidly and other ripening processes to be also accelerated. Fruit ripened in ethylene has a higher sugar content than that ripened in air.

The following table gives the average ripening period and subsequent storage life of tomatoes ripened under different conditions.

TABLE 54.—RATE OF RIPENING AND KEEPING QUALITY OF FRUIT, AS INFLUENCED BY METHOD OF RIPENING

Variety	Condition of fruit	Temperature °C.	Average number days to ripen	Average number days fruit remained edible, at 10 to 24°C.	
				After ripening	After picking
Earliana...	Picked green, air ripened	22	11.3	25.9	37.2
Earliana...	Picked green, ethylene ripened	22	6.5	26.8	32.8
Stone.....	Picked green, air ripened	20	13.2	14.0	28.9
Stone.....	Picked green, ethylene ripened	20	6.2	15.0	26.1
Stone.....	Picked turning	..	....	14.1	22.7
Stone.....	Picked pink	..	....	16.0	19.7
Stone.....	Picked ripe	..	....	11.6	11.6

The softening, to which the final breakdown of the fruit is due, is apparently not accelerated so much by ethylene as are other ripening processes; hence, artificially ripened tomatoes have satisfactory market qualities. To eliminate the immature, flavorless tomatoes on the market, the green fruit should be placed in ripening rooms with ethylene or propylene and fruit not fully colored after 7 or 8 days discarded. Of the fruit, 5 to 10 per cent would be lost, but this fraction consists of that which is very immature and not edible when marketed.

Storage of Tomatoes.—Tomato fruit cannot be stored long either in the green or in the ripe condition. Low temperatures retard ripening and

softening, but, if continued for a long period, breakdown of the fruit ensues. Short periods at low temperatures are not injurious, however. Diehl (1924) found that green fruit held at −0.5 to −1.1°C. for one day without actual freezing ripened afterward, but when held at 0°C. for 8 days or longer, did not ripen upon removal to favorable temperatures. If normal ripening was to be obtained afterward, 4 or 5 days at 0°C. seemed to be about the limit. Fruit picked in the turning condition was somewhat more resistant to prolonged storage at low temperatures than was green fruit. Rosa (1926) found that subsequent ripening was retarded and the per cent of fruits showing breakdown increased, as the storage temperature was lowered. Considerable breakdown resulted from 10 days at 4°C., or 15 days at 8°C. Between 12 and 15°C., ripening is slow, but breakdown is not likely to occur; hence, this range is best for storage. Small fruited varieties (Red, Pear, Orobia) remain sound after becoming fully ripe, at ordinary temperatures, for a much longer period than large varieties.

Adams (1923) also observed the failure of tomatoes to ripen after storage at 0°C. He concluded that they should be picked three-fourths ripe and stored in ventilated rooms at 1 to 2°C., with low humidity. Firm, ripe fruit was then obtained at the end of 3 weeks.

Marketing

Grades.—The grades of the United States Department of Agriculture for tomatoes are as follows:

U. S. Grade No. 1 consists of firm, ripe, fairly smooth fruit, free from molds or decay and from damage by growth cracks, wormholes, "cat faces," scars, sun scald, freezing injury, or mechanical means and not less than 2 inches in diameter. A tolerance of 3 per cent is allowed on size and 5 per cent on defects.

U. S. Grade No. 2 requires fruit similar to U. S. Grade No. 1, but the extent of defects allowable is somewhat greater.

U. S. Grade No. 3 requires only that the fruit be free from mold and decay.

The U. S. grades apply particularly to quality; in the produce trade, sub-grades are recognized, according to the size of the fruit or the number of fruit contained in a standard package.

Grading machinery is used extensively in the tomato-packing houses in Florida. Before grading, the fruit may be passed through a washer containing a disinfectant. As long as the epidermis of the fruit is uninjured, there is little danger of the entrance of decay organisms. Efforts to prolong the storage life by coating the fruit with paraffin and other preparations have not been successful.

Packages.—The principal shipping packages for tomatoes are the six-basket carrier, the four-basket flat, the New Jersey ⅝-bushel splint basket, the 12-quart climax basket and the 30-pound California lug. Each of these containers is favored in one or more of the important shipping districts (Parsons, 1922).

Soft, tissue-paper wrappers on the individual fruit are generally used, especially for long-distance shipments. Wrapped fruit stands the long journey to market better than unwrapped. The practice, however, is an item of additional expense, and wrapping does interfere with normal ripening of the green fruit.

Producing Districts.—Since tomatoes are grown for several purposes and are used in the fresh condition throughout the year, it is not surprising that production is widely distributed.

The east coast of Florida, centering at Miami, is the leading early-tomato section. Mild winters make it possible to grow the crop for shipment from February to April. Western Florida ships in April and May. In the Crystal Springs district of Mississippi, the crop matures about the time the Florida shipments begin to decline. The shipping season is in June, with very heavy shipments for 2 or 3 weeks only. Other districts in the order of shipping season are: Jacksonville, in eastern Texas; Humboldt, in western Tennessee; Union County, in southern Illinois; Swedesboro, in southern New Jersey; and Marietta, in Ohio.

California has several districts which supply western markets from May until December and which ship heavily to eastern markets during the fall. The Imperial Valley ships in May and June. The Los Angeles district is most important for fall shipments. From September to December, after disease has killed the plants in the South and frost has

TABLE 55.—SHIPPING SEASONS AND CARLOT MOVEMENT OF TOMATOES FROM LEADING SHIPPING STATES

State	Principal shipping season	Carloads, average number 1917–1921	Number of carloads annually in recent years				
			1922	1923	1924	1925	1926
California	April to December	2,102	2,346	3,296	2,788	2,961	4,279
Delaware	July	764	413	327	26	32	3
Florida	January to June	4,596	10,261	9,791	9,128	7,163	4,139
Indiana	August to September	917	1,332	1,185	1,479	1,889	1,476
Mississippi	June	1,431	3,441	2,144	3,776	3,149	3,492
New Jersey	July to October	2,627	1,930	1,648	2,150	1,907	2,025
New York	August to September	1,059	1,902	1,261	954	1,024	577
Ohio	July to August	563	557	956	1,035	1,286	1,042
South Carolina	June to July	.....	145	431	421	568	444
Tennessee	June to July	694	920	501	985	1,393	2,374
Texas	May to June	1,378	1,886	1,091	1,694	2,390	2,883
Utah	August to October	.....	.....	.....	.....	1,457	258
Total for whole United States			26,723	24,005	26,817	28,221	25,472

destroyed the crop in the North, there is a demand for California tomatoes on the markets of the whole country.

Table 55 shows the principal shipping sections with their approximate shipping seasons and their annual carlot shipments. The wide variation in annual shipments from various districts is due to changes in acreage, weather, and market conditions. In marketing, much depends on the seasonal production and shipments from the various competing districts. Tomatoes are shipped almost throughout the year. Shipments increase during the early spring until a peak is reached in June. The total number of cars shipped during July and August is relatively low. This is the period of local production in the North and East, so that carload shipments from outside districts are not needed. Late in August, shipments begin to increase again; the market on tomatoes improves at this season, due to exhaustion of home-grown supplies in the East. During the fall, there is a second peak of shipments, which declines rapidly as frost kills the plants in eastern districts. After the first week of October, California is the only important shipper of tomatoes. By the middle of December, the only shipments are those from Mexico.

Tomatoes are grown extensively by market gardeners all over the country. These supply the local markets during the summer period, while the southern and Pacific coast regions furnish carlot shipments in fall, winter, and spring. Large quantities are imported during winter from the west coast of Mexico; these enter at Nogales, Ariz., and are distributed chiefly over the western half of the country.

Tomatoes for Manufacture.—Southern New Jersey, Delaware, Maryland, southern Indiana, southwest Missouri, the Utah Valley, and the Sacramento and Santa Clara valleys in California, are the most important districts. Production of manufacturing tomatoes is mostly confined to a belt from east to west across the central part of the country, far enough south to have a fairly long growing season but not far enough to be subject to excessive damage from diseases, which are favored by high temperatures and high humidity.

The annual pack of canned tomatoes in the more important states is given in Table 56. The usual ratio is about 23 cases of No. 2½ cans packed per ton of fruit.

Surveys in New York, New Jersey, and Maryland show that the margin of profit on canning tomatoes may be small, unless the yield is large; in fact, the crop is often grown at a loss. In New York, Norton (1922) found that when the yield was below 5 tons per acre, the average cost of production was $43.56 per ton; yields of 5 to 10 tons per acre cost $19.51; 10 to 15 tons, $13.01; over 15 tons, $10.15. It is more economical to produce crops of large yield, through the use of manures, good plants, and improved farming methods. Though the total expense per acre is increased, the net returns are much greater.

TABLE 56.—YIELD PER ACRE AND CASES CANNED OF TOMATOES IN LEADING CANNING STATES

State	Average for 1918–1922		1923		
	Yield, tons per acre	Number of cases packed	Acreage	Yield, tons per acre	Number of cases packed
Maryland	3.7	3,477,300	44,230	5.5	5,722,000
California	6.2	1,730,920	27,760	6.2	2,397,000
Indiana	4.5	892,763	66,020	2.9	717,000
Virginia and West Virginia	3.1	934,056	12,900	4.2	963,000
Missouri	2.8	483,510	20,240	2.4	839,000
Delaware	3.5	377,400	17,500	5.3	1,216,000
Utah	10.0	557,321	4,890	8.8	584,000
New York	7.3	380,301	11,700	4.0	266,000
New Jersey	4.6	339,350	20,010	4.7	412,000
Ohio	5.3	184,330	13,860	4.6	174,000
United States, total	4.4	10,703,000	.....	4.2	14,672,000

The relation of canned-tomato production to population in the different sections of the country is shown by the following list for 1919:

	Cans per Capita
New England states	0
Middle Atlantic states	1.66
South-Atlantic states	13.20
East-North-Central states	1.77
East-South-Central states	0.36
West-North-Central states	0.83
West South-Central states	0
Mountain and Pacific states	3.27

The average consumption of canned tomatoes for the United States is 2.89 cans per capita. Only two sections produce a surplus for shipment to other sections. The South Atlantic section, centering at Baltimore, is favorably situated to reach the larger markets. The Pacific coast likewise competes for the markets of the Atlantic seaboard, because of cheap water transportation. There is also a considerable export trade in canned goods, for which coastal locations have the advantage.

VARIETIES

From the commercial standpoint, only the varieties belonging to the sub-species *L. esculentum* var. *commune* are important. Of these, about 468 varietal names were listed by American seedsmen in 1920. A leading seedsman estimates that at least 90 per cent of the catalogued names are unnecessary.

Halstead (1904) made a classification of varieties, which is useful chiefly to show the diversity of forms and characters in the cultivated tomato. The following is a condensed outline of his classification:

A. Plants standard, not potato leaved:
1. Fruit red, Stone.
2. Fruit purple, Globe.
3. Fruit orange yellow, Golden Queen.
4. Fruit lemon yellow, Honor Bright.

B. Plants standard, potato leaved:
1. Fruit red, Mikado.
2. Fruit purple, Magnus.

C. Plants dwarf:
1. Fruit red, Dwarf Stone.
2. Fruit purple, Dwarf Champion.
3. Fruit orange yellow, Yellow Prince.

D. Small Fruited:
1. Currant form, Red Currant.
2. Cherry form, Red Cherry, Yellow Cherry.
3. Plum form, Red Plum, Yellow Plum.
4. Peach form, Red Peach, Yellow Peach.

Within most of the classes, there are sub-classes having small, medium, or large fruit and varieties that are early, midseason, or late in maturing. The most important varieties commercially are described below.

Earliana.—There are many strains of this variety, varying in smoothness and size of fruit. The plant type is distinct; it is small and decumbent, with finely divided leaves. The fruit is red, small, and matures very early. The older strains have a large proportion of fruit which is flat and rough. Improved strains are perfectly smooth and nearly round. Because of its extreme earliness, this variety is much used by market gardeners. June Pink is a pink-fruited strain of Earliana.

Bonny Best (Chalk's Jewel, John Baer).—These varieties are indistinguishable from each other. The plants are of the standard type. The fruit is smooth, red, medium sized, and round-oblate and matures early. This variety is grown for early market in the northern and middle-Atlantic states. In the North, where earliness is necessary to produce a good yield, it is used to some extent for canning and for the manufacture of tomato products.

Globe (Livingston's Globe, New Globe).—The plants are of standard type, but the leaves are broad and of a light-green color. The stems are straggly and have long internodes. The fruit is purple, small to medium size, and rounded or somewhat elongated in shape. It is firm and stands shipment well. The season of maturity is medium early. Globe is the variety most generally grown for long-distance shipment, except in California.

Stone.—Varieties supposedly distinct but nevertheless very similar are Greater Baltimore and Matchless. Norton is a strain of Stone, resistant to the Fusarium wilt disease. The plants are of standard type. The fruit is large, smooth, and medium late in maturity. It is the most popular type for canning in the East. In California, it is grown extensively for shipment. The fruit is meaty and free from hard, white cores, though the locules are large and their contents somewhat watery.

Ponderosa.—The plant is of the standard type. The fruit is very large, flattened, and generally rough at the stem end, with many small locules and a large, meaty core. Though late in maturing, it is the favorite variety for home-garden planting.

San Jose Canner.—This name is applied to a red-fruited variety resembling Ponderosa but is probably derived from Trophy. It is extensively grown in California for canning. The fruit is very large, inclined to be flat and rough, and late in maturing. The cores are large and often permeated with white, woody tissue. The yields are very heavy, and the quality is good, aside from the roughness and undesirable cores, defects which cause a large per cent of waste in canning. Improved strains, which have relatively smooth fruit, have been developed by the California Experiment Station.

Breeding

The tomato has been a favorite material for genetical studies, though much of the credit for its improvement and for the development of present-day varieties is due to practical breeders, seedsmen, and gardeners.

Selection.—The story of Josiah Livingston, of Columbus, Ohio, illustrates the method by which many varieties have originated. After several years' effort to improve tomatoes by selection of single fruits of good type, he observed an unusual plant bearing uniformly desirable fruit; this suggested to him the selection of plants according to the type of all its fruit. Livingston's first variety, Paragon, was introduced in 1870. Subsequently, he developed many varieties, such as Stone, Globe, Beauty, Truckers Favorite, and others. More recently, advances have been made in breeding for disease resistance, earliness, and adaptation to special purposes and special regions.

Individual plant selection presupposes that differences exist within the variety. Though the tomato is mostly self-pollinated, the small amount of crossing which occurs naturally has frequently led to new forms. Mutations have apparently also played a part. Norton (1910) reports several unusual types, some of which were probably somatic mutations and others, due to appearance of recessive characters as a result of normal segregation. MacArthur (1925) reports a chlorophyll-deficient chimera, involving a whole branch but arising from a single mutant cell

in the main stem. Lesley and Mann (1925) report the occasional occurrence of triploid tomato plants. Such plants are often gigantic in size, but because of the sterility of their pollen, generally set few fruits. From the progeny of triploids, trisomic plants have been obtained, with one or more extra chromosomes. Such plants may be very different from the variety from which they came. Mrs. Lesley (1925) also found chromosomal chimeras in the tomato, wherein portions of their tissues were tetraploid. Thus, there are several methods by which variations may arise in a tomato variety.

Most varieties may be assumed to consist of a mixture of lines or biotypes varying slightly from each other. By simple plant selection in such varieties, lines differing somewhat in yield and other characteristics are established. In general, all the gain in a selection is apparent the first season after the selection is made. In other words, it is generally impossible to effect a gradual change by further selections. The futility of selection within a pure line of a self-fertilized plant is well known.

Myers (1914) made individual plant selections in Earliana, Chalk's Jewel, and Matchless varieties; on testing the progeny, he found some to be inferior to the plant selected, others equally good, and others even better. The superiority of some of the original plants selected must have been due to environmental rather than to heritable causes. Myers' experiments showed that lines superior in yield, size, and uniformity of fruit were isolated in the first generation; there was no cumulative improvement from subsequent selections within these strains. Hayes and Jones (1916) ound that self-fertilization for four generations isolated, in the first inbred generation, strains which varied above or below the original variety in yield. Lesley and Rosa (1926), as a result of 3 years' inbreeding and selection with the Santa Clara Canner variety, isolated lines differing in smoothness size, shape, color, and earliness. Some of these lines were constant after the second generation, but others were still variable after three generations. In making selections for a smooth-fruited type from a variety having irregular, rough fruits, Lesley and Rosa used as an index the mean ratio of the polar diameter to the length of the fruit; a small value of this ratio was found to be correlated with a shallow stem-end depression and freedom from the corrugations of the rough fruit. Starring (1925) made selections for earliness and yield in the Bonny Best variety. The progeny of these selections did not give any significant differences in production from the parental variety, which, therefore, was probably homozygous for the characters considered in the selection work.

Plant selection has been used in developing disease-resistant strains. Durst (1917), noting that different varieties showed a varying percentage of wilt on infested soil, by selection of apparently naturally resistant plants developed strains that were capable of living through the season

on infested soil and produced a satisfactory crop. One of his selections was named New Century.

Edgerton and Moreland (1920) selected a wilt-resistant strain from the Acme variety. This was crossed with Earliana and, after several years of selection in the hybrid progeny, two highly resistant early varieties were isolated—Louisiana Pink and Louisiana Red. Pritchard (1922) developed several wilt-resistant varieties, notably, Norton, Norduke, and Marglobe. As to the possibility of increasing resistance through further selection within selected lines, he states that, in a few instances, increased resistance to wilt was obtained by a second selection but that there was no cumulative gain from still further selections. Plants selected from commercial varieties usually transmitted to their progeny about the same degree of resistance as the parent plant. Pritchard crossed a wilt-resistant variety, Marvel, with Globe. From the progeny he obtained a variety, Marglobe, which is resistant to wilt and to the nail-head spot disease (*Alternaria*). Stuckey (1916) found in selections of the Globe variety, that relative susceptibility and resistance to blossom end rot were transmitted.

Inheritance.—Many characteristics of plant and fruit are inherited as unit factors, showing complete dominance or recessiveness in the F_1 and Mendelian segregation in the F_2 generation. The following table gives results on some characters:

TABLE 57.—INHERITANCE OF SOME CHARACTERS IN TOMATO

Characters involved	F_1	F_2	Authority
Serrate leaf × potato leaf	Serrate	3 serrate:1 potato	Groth
Currant leaf × standard leaf	Currant	.....	Price and Drinkard
Green leaf × yellow leaf	Green	3 green: 1 yellow	Price and Drinkard
Simple inflorescence × compound	Simple	3 simple: 1 compound	Crane
Standard plant × dwarf plant	Standard	3 standard: 1 dwarf	Hedrick and Booth
Red endocarp × yellow endocarp	Red	3 red: 1 yellow	Price and Drinkard
Yellow epicarp × colorless epicarp	Yellow	3 yellow: 1 colorless	Price and Drinked
Non-constricted × pear fruit	Non-constricted	3 none-constr.: 1 pear	MacArthur
Smooth fruit × pubescent fruit	Smooth	3 smooth: 1 pubescent	Price and Drinkard
Regular fruit × fasciated fruit	Regular	3 regular: 1 fasciated	MacArthur

Many characters, especially those of a quantitative nature, show partial dominance or are intermediate in the F_1, with a wide range of intermediate forms in F_2. In fruit shape, Price and Drinkard (1908) found spherical partly dominant to pyriform. The neck of pear-shaped fruits was absent in the F_1 but reappeared in 15.4 per cent of the F_2 plants. In crosses between other varieties involving the same characters, Hedrick and Booth (1907) obtained 28.3 per cent pear shape in F_2. In crosses between conical- and oblate-fruited varieties, Price and Drinkard observed an apparent dominance of the conical form. Halstead (1905) concluded that factors for long polar axis of fruit were dominant. No

doubt, other factors have some influence on shape. Thus, the number of locules largely determines the equatorial diameter of fruit. The bilocular form was found by Price and Drinkard to be almost completely dominant to plurilocular. Synanthy, or fasciation, which results in fruits with an increased number of parts, also influences fruit shape; the more fasciated the pistil, the rougher and more oblate, the fruit. Warren (1924) concluded that while fruit shape could not be explained on the single-factor basis, neither was it in accord with the multiple-factor hypothesis. He found that deep fruit (long axis) was produced by the action of two complementary factors, *A* and *B*; smooth fruits (non-fasciated), by two other complementary factors, *F* and *E*. Varieties, or plants, such as Globe, which are dominant homozygotes for both pairs (*AABBFFEE*), have deep, smooth fruits. Varieties carrying the dominant allelomorph of the first pair and recessive for the second pair (*AABBffee*) are deep and much fasciated, like Ponderosa. Other combinations of these four factors give the genotype for fruit shape in other varieties.

Size of fruit is another quantitative hereditary character. Although generally attributed to multiple factors, Lindstrom (1926) shows that small size is partially dominant to large. That definite factors for size exist and that they depend on the same chromosomal mechanism which determines qualitative inheritance is also shown by Lindstrom.

White (1924) found resistance to Fusarium wilt to behave as a recessive character. Stuckey (1916), observing that two-loculed varieties were immune to blossom end rot, made crosses between them and plurilocular forms. The F_1 generation was intermediate as to fruit characters and immune to the disease. In the F_2, there was much variability in fruit type, but all were immune. In subsequent selections toward the large fruited forms, however, this immunity was lost.

Linkage.—Hedrick and Booth (1907) noticed that some characters recombined in the F_2 generation, so that the grandparental forms were recovered. There was a deficiency in the number of some combinations expected in the progeny of the dihybrid cross and an excess in the numbers of others. This phenomenon, known as "linkage," is due to the fact that the genes responsible for different characters are not transmitted independently. According to the chromosome theory of heredity, such genes are located in the same chromosome, hence are usually transmitted together. Since the gametic chromosome number is only 12 (Winkler, 1916), many genes must be linked. Hedrick and Booth observed partial linkage between dwarf-plant type and round fruit, and between standard-plant type and constricted fruit. Jones (1917) also found linkage in these characters, there being about 20 per cent crossing over. Lindstrom (1925) reports linkage between standard-plant and non-pubescent fruit, with only 2.5 per cent crossing over. In 1926, he reported linkage between yellow skin and certain major factors for size of fruit. To a

lesser extent, red-flesh color was also linked with factors for size. MacArthur (1926) found that the genes for four characters in the first chromosome group are linked, as follows, the per cent of crossing over increasing as the closeness of linkage decreases:

Dwarf and pubescent	Crossing over 0.5 per cent
Dwarf and pear	Crossing over 13–20 per cent
Pubescent and pear	Crossing over 17.5 per cent
Dwarf and type of inflorescence	Crossing over 20 per cent

Independent of the above group and of each other, and therefore borne in separate chromosomes, are the five factor pairs controlling fruit-flesh color, fruit-skin color, foliage color, shape of leaf, and fasciation.

Heterosis.—The F_1 plants of crosses between varieties of tomatoes often exhibit hybrid vigor to a marked degree. Groth (1911) noted that the cotyledons in hybrid tomatoes exceeded the mean of the parent varieties in size and, in some cases, even exceeded the larger parent. The same was true of length, width, and degree of segmentation of the leaves. Wellington (1922), in Minnesota, tested 60 F_1 hybrids of 14 different intervarietal combinations. In 21 cases, the hybrids surpassed the more productive parent in number of fruits ripened. In yield of early fruit, 33 out of the 60 hybrids gave an increase over the earlier parent. They produced an increase in total number of fruit for the whole growing season, compared to the mean of their parents, and over half of them produced more than did the highest parent. In some crosses, the hybrids produced larger fruit than did either parent. Comparing the total yield for the whole season, Wellington found that 25 of the crosses gave more than their most productive parent gave. The crosses between very early and second-early types gave the best results in earliness, total yield, and smoothness of the hybrid progeny. Some varietal crosses found to be most favorable for the expression of hybrid vigor were: Chalk's Jewel × Earliana, Globe × Earliana, and Globe × Dwarf Aristocrat. The fact of the decumbent plant habit of Earliana being dominant in F_1 and of its roughness of fruit's being recessive makes it especially desirable to use in crosses where earliness is wanted.

Hayes and Jones (1916) found that the cross, Stone × Dwarf Champion, gave earlier fruit and an increase in yield of 11 to 17 per cent over the better parent, in a 4-year test. They emphasize that not all crosses exhibit hybrid vigor but state that when once a desirable cross is found, it may be expected to give increased yields every time it is made. Heterosis is most pronounced in crosses between varieties which are quite distinct from each other. Frimmel (1925) estimated that a man could cross enough flowers in 30 days to produce about 4 pounds of seed. Considering the commercial value of increased earliness and yield, the cost of the seed would not be prohibitive.

Seed Production

The individual grower may select and save his own seed, but most of it is produced by commercial seed growers. Seed production and handling is a specialized business. Fields intended for seed production should be planted with carefully selected stock seed, and there should be only one variety in the field, to avoid cross-pollination. When the fruits begin to mature, inspection may reveal plants bearing off-type fruit, and such plants should be removed.

Fruits intended for seed production are not generally used for other purposes. Theoretically, seed production can be combined with the manufacture of catsup or paste, but there is danger of mixing the seed of different varieties.

In seed extraction, the ripe fruit is passed through a grinder; the pulp is placed in wooden barrels and allowed to ferment for 2 or 3 days. This removes the gelatinous coating from the seeds. Then, by addition of water and stirring, the pulp, skins, stems, and light seeds are floated off, while plump seeds sink to the bottom and can be further cleaned by additional washings. For separation of seed from fermented pulp on a large scale, a long trough, or flume, is used, with catch basins for the seed every few feet. Rapidly revolving "cyclones" are also much used to separate the seed from the pulp.

After washing, the seed is placed in a thin layer on wire trays or is dried by centrifuging. The cakes of dry seed are pulverized, and the seed are passed through a fanning mill and sacked. In regions of uncertain sunshine, the drying may be rapidly performed in a revolving cylinder through which hot air (50°C.) is blown. Seed should be extracted only from fully ripened fruits, since it gains in weight rapidly during ripening. Seed from the late-maturing fruit is lighter than that from midseason fruit. The yield is about 15 pounds per ton of fruit in such varieties as Stone but may be as low as 4 pounds per ton in thick-fleshed varieties, such as the San Jose Canner.

Diseases

Damping Off.—This disease occurs in plant beds. It is due to various soil fungi (*Pythium, Phytopthera, Botrytis*). Under humid conditions, these fungi attack the plants at the surface of the soil, the stem shrivels and turns black, and the top soon falls over. The disease is most likely to occur when the same soil is used year after year for plant beds. The control consists of using fresh or sterilized soil in the plant beds, keeping the plants and the surface of the soil dry, and giving free ventilation. At Cheshunt (1921), it was found that a mixture of copper sulfate and ammonium carbonate, known as the "Cheshunt compound," may be safely applied around growing plants and will control the disease.

Late Blight (*Phytopthera infestens*).—A different strain of this fungus causes late blight of potato. In cool, moist weather, usually in autumn, it causes great loss in Virginia, and southern California. The disease appears first as numerous black spots on leaves and stems. These spots enlarge rapidly, if the weather remains moist, and soon the whole plant blackens and dies. Fruits are affected in all stages of maturity with dark spots like bruises, which enlarge rapidly, and soon the whole fruit decays. Control consists of spraying the plants with Bordeaux.

Early Blight and Nail-head Fruit Rot.—Several species of *Macrosporium* or *Alternaria* are associated with this disease. In the South, it is prevalent nearly every year, being especially destructive in wet weather. On both leaves and stems appear dark-brown dead areas, showing rather definite concentric rings. On the fruit appear numerous sunken lesions, the so-called nail-head spots, which are the cause of much loss of fruit shipped during winter. These lesions develop during shipment, but infection occurs only in green fruit. Rosenbaum and Sando (1920) found that, during ripening, the epidermis of the fruit changed so that ripe fruits could not be infected. Control measures consist of spraying with Bordeaux both in the seed bed and in the field though this is not entirely effective. The fungus is seed-transmitted; hence, seed from diseased fruits should not be used. It also overwinters in decayed-plant material in the soil. The variety Marglobe is said to be resistant to the disease, at least as far as fruit infection is concerned.

Leaf Mold (*Cladosporium fulvum*).—Though seldom occurring in the field, under greenhouse conditions, severe injury often takes place. The upper leaf surface becomes yellowish, and on the lower surface, a velvety, olive-green mold appears. The fungus may also attack the flowers and both green or ripe fruit. On the fruit itself, a sunken back area appears at the stem end, with blackened radial furrows extending into the fruit. Gardner (1925) says that the fungus may invade the pericarp, locule walls, and placentae and frequently enters also the sepals and pedicel. The seed may be invaded both externally and internally, and seed transmission is probable. In dry air, the spores do not germinate, and the mycelium does not grow. The principal control measure is to keep the humidity in the greenhouse low. Spraying with Bordeaux is not effective against this fungus; Sulphur dust, while toxic to the fungus, also injures the plants.

Septoria Leaf Spot (*Septoria lycopersici*).—This disease is estimated to cause an annual loss of 250,000 tons of tomatoes on the canning crop in the United States. It occurs from the middle-Atlantic states westward to the Rocky Mountains. The lesions first appear as small, water-soaked spots on the underside of the leaf. The circular spots enlarge, and the tissue turns dark, becoming hard and dry. In the center of these spots, a greyish mass of the fruiting bodies of the fungus often appears. If

warm, moist weather prevails, the spots continue to enlarge until the leaves are killed; the plants may be defoliated quickly. Small, elongated, brownish lesions occur on the stems, but the fruit is not attacked. The latter, being exposed to the sun, is injured by sun scald or turns red prematurely.

Septoria is disseminated by spores, which germinate in a film of moisture on the leaves, and the mycelium enters the tissues through the stomata. Martin (1920) showed that several insects might carry the spores; but wind and spattering by rain drops are probably the chief methods of dissemination: pickers working in the field when the plants were wet also spread the disease. The fungus overwinters in diseased stems but not on the seed. Pritchard finds that if the dead plants are plowed under deeply in the fall, infection the following year is greatly reduced. Pritchard and Porte (1921) find that the fungus occurs on horse nettle (*Solanum carolinense*) and on Jimson weed (*Datura* sp.) and that the disease is intercommunicable between these plants and the tomato. Pritchard found his wilt-resistant varieties also somewhat resistant to Septoria. Kotowski (1926) found two varieties, P. L. M. (*Italia*) and Holmes' Suprême, to be resistant both to Septoria and to late blight. Resistance to disease seemed to be associated with a greater acidity in the green fruit. Pritchard and Porte (1921) found in pot-culture experiments that nutrients which increased the vegetative growth also increased the susceptibility of the plants to Septoria. These writers suggest also a relation between acidity of sap and resistance to infection.

Early planting, to give the plants a good start before outdoor temperatures become favorable for the sporulation of the fungus (minimum, 15°C.), is an important means of helping the plants to escape Septoria. Spraying with Bordeaux and with copper soap is also effective in control. As far as this disease is concerned, spraying need not be begun until the middle of the growing season, since infection in the seed bed and in the field early in the season is unusual. Spraying with Bordeaux does not always result in an increased yield of ripe fruit. Edgerton (1918) found that, in some cases, ripening of early fruit was retarded where plants were sprayed. This phenomenon may be due to the preservation of the foliage by the spray material; partial defoliation by disease results in earlier ripening, even though later production is curtailed. On the other hand, Pritchard and Clark (1919) found no significant decrease in production of early fruit on sprayed plots in New Jersey, Maryland, and Virginia, but it is not known whether any fungus diseases were present in these experiments. Spraying with Bordeaux is most effective in increasing the yield in the middle and later part of the season.

Fusarium Wilt (*Fusarium lycopersici*).—Only tomatoes are susceptible to this species of Fusarium—a soil fungus which enters the plant through the roots. It is most destructive in the warmer parts of the

country, where it appears a few weeks after the beginning of hot weather. The lower leaves of affected plants turn yellow and dry. The stems, if split open, reveal brownish discoloration in the wood. The disease advances rapidly, killing either the entire plant or some of the main branches. There is no true wilting of the plant. The fungus mycelium is found in the vessels of the stems but not in sufficient amount to plug them. Death of the plant is due to a toxin secreted by the fungus. The wilt fungus has been proven by Elliott and Crawford (1922) to be transmitted to a limited extent in the seed. Transfer of infected soil or animal manures and of plants from infected seed beds are other common means of dissemination.

The growth of the wilt organism and its ability to produce disease are limited by the temperature. Clayton (1923*A*) found the optimum soil temperature for the fungus to be 28°C., though at 31°C., it developed almost as virulently. Below 21°C., the disease was practically inhibited. The upper temperature range for the fungus is the same as that for the plant, but the plant can grow at temperatures too low for the fungus. Hence, tomatoes are not affected by Fusarium wilt in cool regions. Clayton (1923*B*) found also that plants growing very rapidly as a result of optimum soil-moisture conditions were most susceptible to wilt infection, while checking growth by withholding water inhibits the development of the disease. This is evidence against the theory that death of the infected plant is due to water deficit. Plants growing in saturated soil were, however, not susceptible to the disease; their immunity must be due to a change in the plants tissues, for the fungus can grow in liquid media.

Sherwood (1923) found 100 per cent infection in soil at Ph 5, but as the soil was made less acid by addition of lime, the percentage of infection decreased. At Ph 6.8 to 7.0, the infection was 30 to 64 per cent; at 7.4, 10 per cent, at 8.2, no wilt. But the plant growth at Ph 8.2 was not satisfactory. Scott (1924) found that the minimum amount of wilt occurred in the range Ph 6.4 to 7.0, with increased amounts both on the acid and on the alkaline side of this range.

It is not known how long the wilt organism will survive in infected soil. A 4- or 5-year rotation is said to reduce the amount of infection. Soil known to be free of infection should be used in the plant beds, even though a resistant variety is grown.

Varieties highly resistant to Fusarium wilt have been developed by selection from naturally resistant plants. Marvel, Norton, Marglobe, and Louisiana Red and Louisiana Pink are wilt resistant varieties which have proven commercially desirable.

Verticillium Wilt (*Verticillium albo-atrum*).—This disease resembles in many respects that caused by Fusarium. These wilt diseases, however, seldom occur in the same region, because of the difference in their

temperature requirement. Verticillium wilt is a disease of cool regions, common in Europe, but probably of limited occurrence in America. Bewley (1923) states that 17 to 21°C. are the most favorable temperatures for Verticillium to grow; it is inhibited at 25°C., which is near the optimum for Fusarium. Heavy soils, being cooler, are more favorable for Verticillium than sandy soils. This fungus attacks many other vegetables, fruit trees, and other plants. When introduced into the soil, it is a much more serious disease than Fusarium. Manx Marvel, a variety resistant to Verticillium in England, has not proved resistant in California.

Bacterial Wilt (*Bacterium solanacearum*).—This disease is caused by a soil parasite, which attacks also the potato. It is a true wilt; affected plants droop during the heat of the day and partially recover at night. No yellowing of the leaves appears in the early stages. There is no definite darkening of the stem, but freshly cut diseased stems exude a gummy, yellow mass of bacteria. It is said that the bacteria can enter the roots only through wounds. Removal of diseased plants prevents the transfer of the bacteria to healthy plants by insects.

Bacterial Spot (*Bacterium vesicatorium*).—This disease is prevalent in the Middle West and South on both peppers and tomatoes. On the leaf, small, angular, translucent areas appear. These turn black and become dry without enlargement. Severely spotted leaves turn yellow and fall. Similar lesions, forming cankers, occur on the stems. On the fruit, small, raised black spots occur, with a yellowish zone about them and extending into the fruit. Leaves are infected through the stomata, but as the fruit have no stomata, the bacteria can enter only through wounds. Gardner and Kendrick (1921) found that only green fruit were readily infected, ripe fruit being very resistant. The same workers found that the organism was carried over winter on the seed from diseased fruits and that the plants grown therefrom became infected either in the plant bed or in the field. Seed may remain infected for 2 years or longer. It may be disinfected by soaking for 5 minutes in a 0.05 per cent solution of mercuric chloride, afterward rinsing in water. Formaldehyde is not effective.

Blossom End Rot.—This is a physiological disease of widespread occurrence. Brooks (1914) showed that various organisms were associated with the disease in a secondary way only. The first stage occurs on either green or ripening fruit, as an irregular, brownish patch at the stylar end. If it does not develop beyond this stage, little harm is done. But the lesions may advance until the lower half of the fruit is decayed by a black, leathery rot. It is usually associated with conditions where the plants are not able, on account of dry soil or limited root system, to take up moisture as quickly as it is needed. The trouble also occurs under alkali-soil conditions, where the high salt concentration brings about a condition of physiological drought.

It may occur where plants make excessive vegetative growth early in the season and are subjected to high transpiration conditions later. Adequate moisture supply and a deep and extensive root system aid in preventing the disease.

Stuckey (1915) found that irrigation or the conservation of moisture by a straw mulch largely prevented blossom end rot. His data indicate that limitation of vegetative growth, through withholding of nutrients, may reduce loss by rot. Brooks found the most vigorous plants to be most susceptible. The selection of resistant varieties seems possible.

Sun Scald.—When mature plants are defoliated by diseases, the fruit thus exposed to direct rays of the sun develops collapsed areas near the stem. Varieties which do not make a vigorous growth often have their fruit injured by sun scald, even in the absence of disease. Harvey (1924) found that localization of the scalded area was connected with the dark-green color on the shoulders of immature fruit. This color resulted in considerably greater heat absorption than that which took place in lighter-colored areas. He therefore suggests breeding varieties whose fruit do not have dark-green shoulders.

Yellows (*Western Yellow Blight*).—This blight occurs west of the Rocky Mountains, from Canada to Mexico, and is most prevalent in the hot, dry, inland valleys. No organism has been proved to be the primary cause. However, it has been found that plants become affected only when beet leaf hoppers (*Eutettix tenella*) which bear the virus of the beet curly top disease, have fed on them. Affected plants stop growing, the leaf margins roll upward, the leaf-blades becomes yellowish, and the veins become purpled. The symptoms, including an enormous accumulation of carbohydrates which accompany them, seem to be the result rather than cause of the stoppage of growth. Shapovalov (1925) shows a correlation between seasonal as well as regional occurrence of this disease, with certain combinations of weather conditions. Climatic conditions which cause a high evaporation rate, such as low relative humidity and high temperature, are conducive to development of this blight.

In regions where the disease occurs often, loss can be minimized by setting two or three times the usual number of plants per acre, so that after the loss of a large proportion of them by blight, a sufficient number remain to produce a fair yield. Plants somewhat shaded are much less subject to the disease.

Mosaic.—This disease is generally attributed to a filterable virus, though Miss Eckerson (1926) has observed definite protozoan-like organisms attacking the chloroplasts in mosaic-affected tomato tissues. Mottling and distortion of the leaves, followed by irregular necrotic spots and the stunting of the whole plant, are the usual symptoms. The mottling and necrosis may extend to the fruit also. The infective principle is readily transferrable from plant to plant by insects, by rubbing

with the hands or by juice inoculations. Tomato mosaic occurs also on horse nettle and ground cherry (*Physalis sp.*), and these common weeds with perennial root stocks act as overwintering hosts (Gardner and Kendrick, 1922). Tomato mosaic may be transmitted also to tobacco, peppers, cucumbers, potatoes, and other vegetables, in some cases producing mosaics similar to those usually found on the different hosts (Walker, 1926).

The disease is not seed-transmitted, nor does it overwinter in the soil. Elimination of alternate host plants, control of insects responsible for spreading the disease, and destruction of infected plants are the chief control measures.

Shoestring Mosaic.—This is also a virus disease. It is characterized by extreme reduction in the leaf-blade, which becomes little more than a midrib. Johnson (1926) found that mosaic virus taken from cucumber and from tobacco, when injected into tomato, caused typical shoestring mosaic.

Streak, or Winter Blight.—This is a destructive disease on greenhouse tomatoes. Raised, brown, greasy patches occur on the fruit. The leaves are distorted, reduced in size, and have necrotic patches, which occur also on the stem, especially toward the tip. Some workers have attributed streak to bacterial infection, others to malnutrition or excessive amounts of nitrates in the soil. Vanterpool (1926) proved that streak is due to infection by the same virus which causes mosaic on potatoes in conjunction with ordinary tomato mosaic. It is therefore a combination-virus disease and should be treated as the other mosaics. It cannot be controlled by soil or fertilizer treatments nor by manipulation of other environmental factors, though excessive humidity, high temperature and succulent growth are predisposing factors.

Insect Pests

Horned Tobacco-worm.—This insect often occurs in great numbers. The larvae are large, green or brownish, and voracious feeders and rapidly defoliate the plant. They attack also the fruit. In the South, there are three broods each year. The first brood is usually not very numerous and may be controlled by hand picking. The worms are easily poisoned by spraying the plants with a mixture of arsenate of lead, 3 pounds to 100 gallons of water. Late in the season, when the plants are too large to spray conveniently, dusting with a mixture of arsenate of lead, 1 part to 20 parts of lime, is effective.

Corn Earworm or Tomato Fruitworm.—Though a more serious pest to corn than to tomatoes, these worms sometimes destroy many fruits. Control measures are crop rotation and dusting or spraying with arsenicals. Smith and Zimmerley (1921) found that spraying with Bordeaux plus arsenate of lead reduced the percentage of wormy fruit from 25 to

16 per cent. Because of the effect of the fungicide on diseases, there was also an increase in yield. Markovitch (1925) obtained good control by spraying with arsenate of lead and Kayso, the latter acting as a spreader and sticker. Morrill (1926) reports that in large fields dusted from an airplane with calcium arsenate, the per cent of wormy fruit was reduced from 40 to 4. Trapping of the worms on sweet corn interplanted in the tomato field has been recommended often, but Markovitch finds that this practice leads to increased infestation of the tomatoes. Since the moths of this insect are night flyers, light trapping has been suggested, but it is found that the female moths are not attracted to the lights until they have completed egg-laying.

White Fly.—This insect often becomes so numerous in greenhouses, that considerable injury is caused. The honey dew secreted by them on the fruit provides a medium for the growth of molds, which detract from the appearance of the fruit. Fumigation with hydrocyanic-acid gas is the usual means of control. Clayton (1919) finds that this gas in different concentrations gives effects on the plants ranging from distinct stimulation to severe injury. The maximum stimulation is at the concentrations fatal to white fly and just below that which causes injury to plants. Toxic concentrations vary, however, with temperature and humidity. Injury usually parallels the degree of stomatal opening; hence, fumigation is done at night.

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CHAPTER XIX

CAPSICUM

Although of minor importance as a truck crop in the United States, the various forms of peppers are widely cultivated. The large-fruited, non-pungent, sweet peppers, used as a salad, are grown as a market-garden crop even in the North; the mildly pungent chili peppers are extensively grown for drying, canning, and use in the green condition; thick-walled, smooth-fruited varieties of the pimiento type are canned; very small, extremely pungent-fruited varieties are used for manufacture of tabasco sauce. The long-podded, mildly flavored varieties, introduced from Hungary, are grown successfully in the South for drying and for the manufacture of paprika. The black pepper of commerce is derived from seed of some species of the *Piperaceae*, trees and shrubs confined to the tropics, while red pepper is the powdered, dry fruit of pungent varieties of *Capsicum*.

Taxonomy.—The classification into species by different botanists has varied greatly. Thirty-five species of *Capsicum* were listed by Morison in 1699. Linnaeus (1797) recognized six. By 1852, the number had increased to 50. Confusion in nomenclature is due chiefly to the extreme variability in fruit form and to the frequent appearance of new forms through cross-pollination. · Irish (1898) revised the genus, reducing the number of species to two, *C. annuum* and *C. frutescens*. He gives an excellent key for the classification of the horticultural varieties, which, however, reveals no constant distinction between the two supposed species.

Bailey (1924) combines all peppers into one species, *C. frutescens*, with a number of sub-species, or varietal groups, as follows:

Variety *cerasiforme*.—Cherry peppers, having small spherical or flattened fruit.

Variety *conoides*.—The fruit is small and conical or oblong.

Variety *fasiculatumi*.—Red cluster peppers. The fruit is erect, fascicled, and very slender.

Variety *longum*.—Long peppers. Fruit 3 to 12 inches long, tapering, and often curved. This includes the so-called "chili" varieties.

Variety *grossum*.—The bell, or sweet, peppers. The fruit is very large, thick-walled, and usually non-pungent.

In addition, there is the wild "bird pepper" of the West Indies, with small, slender fruit, generally considered to be the progenitor of the cultivated forms, with which it crosses readily.

History.—All authorities agree that the genus *Capsicum* is native to tropical America. Many forms were cultivated and used as food by the natives of the West Indies, Mexico, and Peru, before the coming of the white men. According to Sturtevant, Columbus took pungent peppers to Europe on his first voyage. The Portuguese took peppers to the East Indies, where they became widely cultivated. Pepper culture became important also in southern Europe, especially in Spain, Greece, and Hungary. In the last country, rather pungent varieties were developed for manufacture of paprika. Non-pungent varieties were used for the same purpose in Spain. It is not known when peppers were introduced into the United States, but three varieties were listed by McMahon in 1806.

Plant Characteristics

The plants are erect, compact in form, and dichotomously branched, with angular, herbaceous stems, which become woody with age. Although peppers may be perennials in the tropics, they are cultivated as annuals in temperate zones. The leaves are flat and glabrous, simple, and entire, varying in shape from ovate to long and narrow.

The flowers occur singly in the axils of the branches and are formed continuously throughout the season. The corolla is either white or purple, rotate, and five-parted. There are five stamens, not united as in tomato. The anthers dehisce by longitudinal splitting. Self-pollination takes place, in general, but there appears to be a considerable percentage of cross-pollination also, for many hybrids have been noticed as a result of growing different varieties near each other.

Fruit.—The fruit is a podlike berry, borne on a short, stout peduncle, erect at first but in some varieties curving downward toward maturity. There are generally prominent, longitudinal ribs, marking the position of the interlocular septae. There are two to four locules, as a rule, though more may occur in large-fruited varieties. The central part of the fruit is occupied by hard, white placentae. The locular septae do not unite in the center, except in the basal third of the fruit. The outer wall, or pericarp, is fleshy and of varying thickness; it consists of (1) a very thin cuticle, (2) five to eight compact layers of small collenchyma cells, which become cutinized during maturation and provide a tough, colorless, epidermal layer, or skin, (3) several layers of large parenchyma cells traversed by the vascular tissue, and (4) a single layer of very large cells bordering on the seed cavity. The growth of the fruit in the early stages consists of rapid cell multiplication; in the later stages, growth is chiefly by enlargement of the cells already formed. In preparing the fruit for canning, the epidermis is removed by a roasting process.

Immature fruit is yellowish to deep green in color, on account of the chlorophyll in the outer layers of the pericarp. Upon maturity, the

fruits become either red or yellow, according to variety. The pigment of red peppers is a mixture of lycopersicin, xanthophyll, and carotin, while carotin alone is present in yellow varieties. Peppers of the sweet

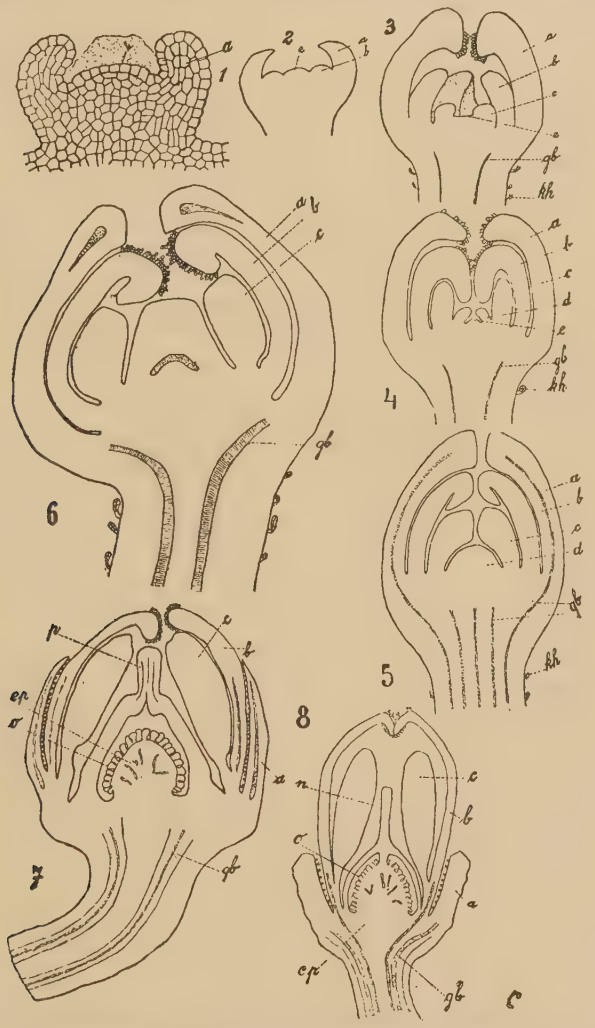

FIG. 51.—The development of the flower in pepper. 1 and 2. Floral primordium. (*a*) Calyx. 3, (*b*) Corolla, (*c*) Stamens. 4 and 5. Showing origin of the carpels at *d*. 6. Beginning of differentiation in the ovary. 7 and 8. Longitudinal section through bud, at stages just before anthesis. (*p*) Pistil, (*o*) Ovules; (*ep*) Placenta. (*After Bela.*)

type are usually eaten green, but those used for canning, paprika, or dry chili, must be of a deep-red color. Green peppers can be ripened artificially in the same way as tomatoes, though a longer period is required. The best temperature for ripening is, according to Miss Howard (1925), 22 to 25°C.

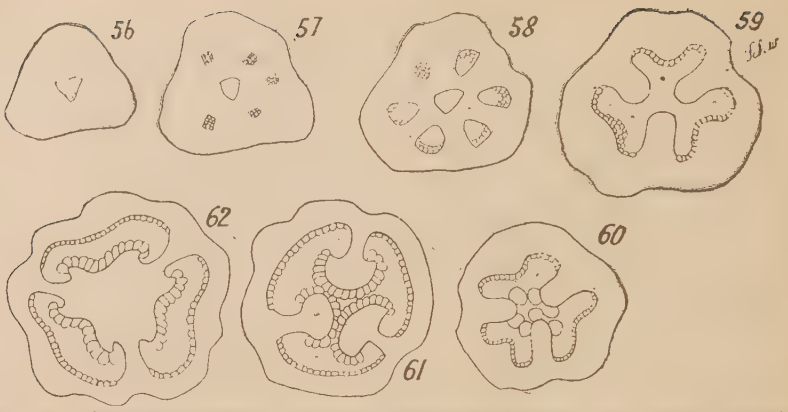

FIG. 52.—Successive sections through a young pepper fruit, from the tip toward the base, showing the orientation of the placenta. Near the tip, it is parietal but at the base it appears to be axile. (*After Bela.*)

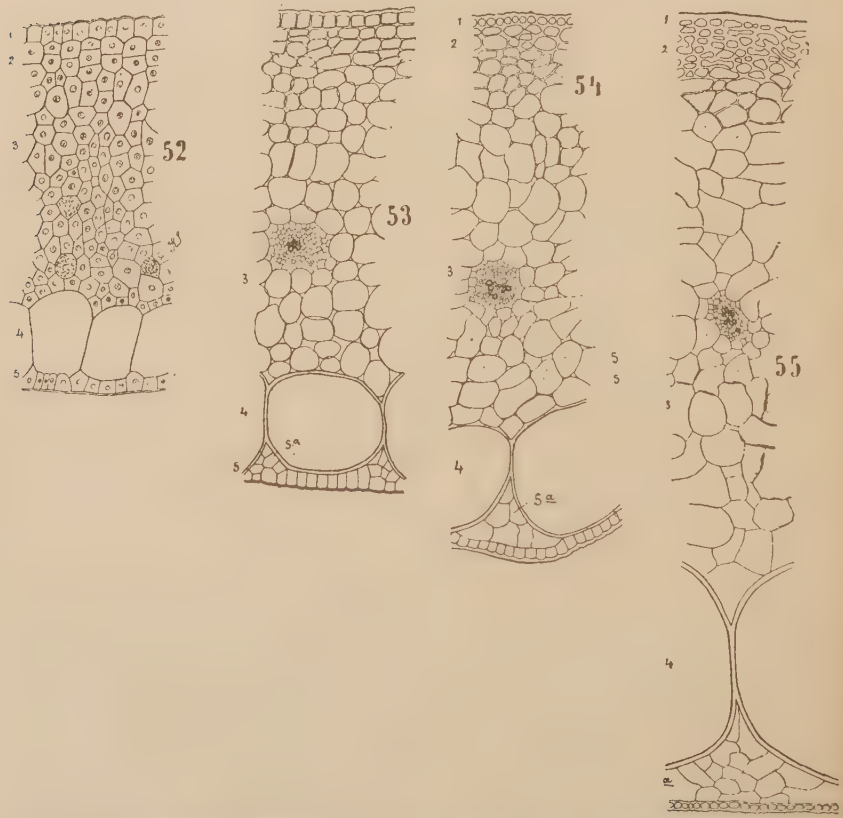

FIG. 53.—Sections through the fruit wall of pepper fruit in different stages of development. Note the dense layer of small cells beneath the outer epidermis and the row of "giant cells" within the inner epidermis. (*After Bela.*)

In the placental tissues of some varieties of peppers occurs the crystalline substance, capsaicin ($C_9H_{14}O_2$), which imparts the characteristic pungency to "hot" varieties. The seeds do not contain this substance but often taste hot because of small bits of placenta adhering to them. The pericarp may be free of capsaicin or may contain it in large amounts. According to Young and True (1913), the most pungent-flavored paprikas and sauces are made by grinding the whole fruit. In whole, dried paprika peppers grown in South Carolina, 15 per cent glucose and 1.2 per cent cane sugar were found while the pericarp alone contained 24.6 and 1.7 per cent, respectively, of these sugars. Among the important factors affecting flavor of peppers are aromatic substances, occurring in very small amounts and not connected with pungency. The seeds contain an oil, which gives a bright color to ground-pepper products. Stuckey and McClintock (1921) give 33 pounds for pimento and 26.5 pounds as the weight per bushel for bell peppers. Of the former, 31.5 and of the latter, 17 per cent was found to be waste (stems, seed, and cores).

Seed.—The seeds are borne in compact rows on the placenta, chiefly at the basal end of the fruit. The seed is flattened and discoidal in shape, with a deep chalazal depression. Like the other *Solanaceae*, the seed coat is derived from a single integument, which, however, becomes divided into three distinct layers in the mature seed (Souèges, 1907). The outer layer of cells is reinforced by heavy cellulose thickenings, especially on the inner and tangential walls. The cells around the edges of the flat seed are considerably elongated, thus forming a marginal band or elevation.

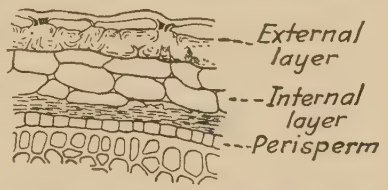

FIG. 54.—Section through the seed covering of pepper. Note the much thickened cells of the external layer. (*After Soueges.*)

From 25 to 30°C. has been found most favorable for the germination of pepper seeds, which usually germinate slowly, requiring about 2 weeks.

CLIMATIC RELATIONSHIPS

Peppers closely resemble tomatoes in their requirements for temperature, length of growing season, and moisture relations. They are, however, better able to withstand extremes of heat and dryness than tomatoes are. They seem also more adaptable to extremes in plant-food and moisture supply. Failure to set fruit does not occur where tomatoes, under the same conditions, would be extremely vegetative and nonfruitful. At the Georgia Experiment Station (1922), it was found that nitrogeneous fertilizers increased plant growth and fruit production but also resulted in greater susceptibility to blossom end rot. Auchter and Harley (1924) found that peppers were not sensitive to the length or

intensity of daily illumination, flowering in about the same time, with 7 or 15 hours of full sunlight daily. Plants grown in diffuse light under cheesecloth shade blossomed at the same time as those receiving full sunlight. Plants receiving the normal daily period of sunlight, however (15 hours) plus electric light all night were much slower in reaching the blossoming stage.

Culture

Cultural practices in pepper production are about the same as for tomatoes. The plants are always started in hotbeds in the central and northern states; field sowing of the seeds is the rule, however, in the Southwest, especially for chili peppers. Because of their small size and erect habit of growth, the plants are spaced closer than tomatoes. In Georgia it was found that spacing the plants 1 by 3 feet gave a greater yield per acre than spacing them 2 by 3 or 3 by 3 feet.

Harvesting.—The change in color from green to red or yellow is the most conspicuous change during ripening. Most varieties, however, except for some pimentos and chilis, are used in the green-mature condition.

The chemical changes during growth and maturation of paprika peppers have been determined by Sievers and McIntyre (1921). The moisture and ash constituents decrease, while the ether extract (fats, and so forth) and reducing and total sugars increase steadily during maturation. Peppers for market should be handled carefully to avoid bruising. The fruit peduncle is cut close to the fruit or broken by an upward twist. Green peppers are picked mainly on the basis of size. Chili peppers for drying are gathered in the fully ripe condition. The loss on drying is less for ripe peppers than for those picked partly green, being about 65 per cent for the former and 75 per cent for the latter, according to Garcia (1908). Chili-pepper fruits are often gathered after frost, which, for drying purposes, does not seriously injure the ripe or nearly ripe fruits.

Marketing

The leading states in production of sweet peppers are Florida and New Jersey; the former state ships peppers in carlot quantities to northern markets during winter and spring. Pimientos are grown and canned chiefly in Georgia and California. Chili peppers are produced most extensively in Orange County, Calif., but some are also grown in Arizona, New Mexico, and Texas. Considerable quantities of canned as well as dry chili are exported to Mexico.

Manufacture.—Chili peppers are either sun dried or dried in kilns. The former, more primitive, method gives a product with excellent color but lower sugar content than does artificial drying. Drying houses, or

kilns, are almost universally used in California for drying peppers on a large scale. These houses are heated with gas burners to a temperature of 55°C. Ventilation is provided by flues through the roof. The peppers are placed in thin layers in wire-bottomed trays stacked one above the other. They must have frequent stirring and be given 2 or 3 days in which to dry. The dry chili is packed in large sacks for marketing. Much of it is ground and sold as chili powder, or the red pepper of commerce. The whole fruit is used, including stems, seed, and placenta. The yield of dry chili ranges from 1,250 to 3,000 pounds per acre.

Paprika.—Most of the paprika pepper used in the United States is imported from Hungary and Spain. Peppers suitable for paprika can be grown in the South, and methods of curing have been worked out. Paprika peppers varies in pungency according to variety used, conditions of drying, and amount of stems and placenta included in the material; in general, it is mild flavored compared to chili or red pepper. The seeds furnish about 30 per cent of the dry weight of the fruit, and their grinding is not objectionable, since they contain an oil which improves the flavor and color. The stems contribute only 9 per cent of the dry weight and, since they consist of woody tissue, should not be included in paprika.

Varieties

Characteristics used in the classification of peppers are: peduncles straight or recurved; calyx embracing base of fruit or not; size, shape, and color of fruit. Such qualities as pungency or the lack of it, color of petals, thickness of fruit wall, and shape of leaves may be found in any varietal group. The numerous varieties may be considered under five natural groups:

1. Bell Peppers.—These are characterized by very large, thick-walled, non-pungent fruit, with longitudinal ridges following the interlocular septae. The fruit usually has a deep depression at both stem and stylar ends and is somewhat irregular in shape. Chinese Giant and Bull Nose varieties have extremely large, blocky fruit; Golden Squash is oblate; Ruby King, Ruby Giant, and Sweet Mountain are elongated. This group is most extensively grown for marketing as green peppers.

2. Pimiento.—The fruit is medium sized, very thick walled, and has a smooth contour externally. In shape, it is oblate, round, pointed, or elongated, according to the variety. The flesh should be non-pungent, but because of accidental cross-pollination with chili peppers, hot pimentos are common. Perfection and Tomato are leading varieties.

3. Small-fruited Sweet Peppers.—These are probably of the same type as those used for manufacture of mild paprika in Europe. They are little grown in America. Early Neapolitan is a typical variety.

4. Chili Peppers.—The word *chili* is Spanish for any kind of pepper; but in the United States, the term is limited to mildly pungent varieties

used mostly in the dry state for flavoring other foods. These varieties have little or no depression at the stem or stylar ends of the fruit, which is rather long and slender, thin walled, and mildly pungent both in pericarp and placenta. The Anaheim, or California, variety has longer, thinner-walled, and more pungent fruit than the Mexican.

5. Small Hot Peppers.—Small, long, slender, smooth-fruited, and extremely pungent varieties, such as Long Cayenne and Tabasco, may be included in this class.

Breeding

Little systematic breeding work has been done on peppers. Varieties have been developed simply by selection of desirably shaped fruits. The varieties are often ununiform, because of their heterozygosity for many factors resulting from naturally occurring cross-pollination.

Webber (1911) determined the mode of inheritance of several characters, which is given in the following table:

Allelomorphic characteristics	F_1 condition	F_2 behavior
Violet × white flower	Violet of varying intensity	3 violet: 1 white
Non-umbel × umbel inflorescence	Non-umbel	3 non-umbel: 1 umbel
Red × orange fruit	Red	3 red: 1 orange
Pubescent × glabrous stems	Intermediate	15 pubescent: 1 glabrous
Pungent × sweet	Pungent	3 pungent: 1 sweet

He observed that violet flowers were associated with purple pigmentation of leaves, stems, and immature fruit, whereas white flowers are associated with green plant parts. Size of leaf and size of fruit were evidently influenced by several factors. Ikeno (1913) obtained results similar to those of Webber as to size inheritance and, in addition, showed that the character of the peduncle, whether erect or recurved, depended on a single factor difference, recurved being dominant.

Webber obtained gigantic plants in the F_2 generation of a cross between Red Chili and Golden Dawn, as a result of a combination of factors for many, fine, erect branches from one parent and few, coarse, horizontal branches from the other. Halstead (1912), in crosses between Bird's Eye and several larger-fruited, cultivated varieties, showed that complete abscission of the mature fruits of the former was dominant over persistance of the latter. Long pods were partially dominant over short pods or oblate fruit.

Diseases

Anthracnose or Fruit Spot.—This disease has been variously attributed to *Colletotrichum nigrum* and *Gleosporium piperatum*, and

several other fungi have been isolated from the diseased spots. Higgins, however, (1926) found that these were all secondary invaders, or wound parasites, except for the *Gleosporium*, which is an active parasite. Ripening fruit is more susceptible than immature fruit; hence, this disease is seldom a serious factor where only green peppers are produced. All varieties, both sweet and pungent, are susceptible.

The spots on the fruit begin as water-soaked or darkened, depressed areas, which enlarge rapidly in wet weather, turning lighter in color, then become overspread with the black fungus growth.

The fungus overwinters on seed from infected fruits, and seed disinfection is an important preventative for the disease. Soaking the seed for 5 minutes in 0.1 per cent mercuric chloride or for 10 minutes in 1.6 per cent copper sulphate, followed by dusting with slaked lime, is recommended by Higgins (1923*A*). The seed is sensitive to disinfectants.

Bacterial Spot.—The same bacterium causes a spot disease on tomatoes. Leaves, stems, and fruit are attacked, the lesions consisting of small, circular spots of water-soaked or brownish tissue. Seed disinfection is the most important control measure.

Blossom End Rot.—Apparently physiological in nature, this disease is a cause of serious loss in dry weather, over 90 per cent loss being reported by Higgins (1925). It is first manifested by slight depressions of pale tissue at or near the stylar end of half-grown fruits. Infection by various bacteria and fungi follows. Injury from this disease has often been ascribed to *Alternaria* and *Macrosporum*, common parasites attacking weakened tissues. Withholding water during the growing season from plants previously watered freely induced the disease in 10 to 30 days (Higgins). Fruits approaching maturity may show the primary breakdown without subsequent decay. Since the vascular system appears ample to supply the tops of the plants with water, the roots seem to be the limiting organ of water supply.

Other Diseases.—Damping-off disease often attacks seedlings in the plant bed. A blight caused by *Sclerotium rolfsii* is common in the South; since this fungus lives in the soil and attacks many species, it is difficult to control. A wilt disease, caused by *Fusarium annuum* occurs in New Mexico; it is said to be controlled by growing the plants on high beds, so that the soil around the stem is never saturated by irrigation water. Rots, caused by various weakly parasitic fungi, occur on the fruit, usually following mechanical injury to the epidermis. The foregoing diseases, and others occasionally occurring on peppers, have been described by Higgins (1923*B*).

Insects

Pepper Maggot (*Spilographa electa*).—This insect has been reported as occurring in New Jersey, in the fruit of both peppers and eggplant.

The adult females puncture the young fruit and deposit eggs within; the larvae tunnel through the placenta. Infested fruit is misshapen and ripens prematurely. Infestation in Ruby King and other elongated peppers is said to be less common than in the round varieties (Peterson, 1923).

Pepper Weevil (*Anthonomus eugenii*).—Closely resembling the cotton boll weevil in life history and habits, this insect likewise came from Mexico, has long been known in Texas, and, in 1923, appeared in California. It has multiplied rapidly and is the cause of extensive loss in the southern part of that state. Adults emerge from hibernation late in spring, and the early fruit may escape, but infestation is severe on late fruit. Eggs are laid in young fruit, and the borings of the resultant larvae prevent its development. Infestation of fruit nearing maturity does little damage. All kinds of peppers are attacked. Pupation occurs in the fruit, and the adults overwinter in dried fruit and other plant remains. Dusting with arsenate of lead is the chief control measure. Burning all trash and plowing the fields as soon as the crop is harvested will, according to Campbell (1924), greatly reduce the number of adults surviving the winter. Breeding early varieties and early planting of the crop are also likely to aid in preventing weevil injury.

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CHAPTER XX

SOLANUM

SECTION A. POTATO

The so-called "Irish," or "white," potato is by far the most important of our vegetable crops; in fact, it is second only to rice as a world food crop. Besides their use as human food, the use of potatoes as stock feed and for the manufacture of starch and alcohol and for other industrial purposes is extensive. Potatoes are grown in all parts of the United States, though commercial production is becoming more concentrated in certain areas having the most favorable soil and climatic conditions. The potato has been the subject of an enormous amount of investigational work. In 1878, De Vries wrote, "The extent of potato literature has become so great that it is hardly possible to master it." Since his time, the volume has increased manyfold. Present knowledge as to the effects of virus diseases on the plant has invalidated much of the older work, for, in many cases, no doubt, conclusions have been drawn from experiments with diseased plants.

Taxonomy.—Potatoes belong to the genus *Solanum*, the cultivated potato being assigned to the species *tuberosum*. Berthault (1911) lists 36 other species of tuberous *Solanum*. The wild species, in general, have slender, trailing plants and bear small, irregular tubers. Much effort has been expended by botanists in trying to determine which of the wild species is the parent of the cultivated type; *S. maglia*, *S. commersoni*, and *S. chiloensis* have been most considered in this regard. It is not certain that the cultivated potato is a direct descendent of these or any other wild species. Labergerie (1904) claimed to have gotten several large-tubered forms from *S. commersoni* as mutations arising through the influence of cultivation on this wild species. His results have not been generally accepted, however, for other investigators have found the wild species to remain constant under cultivation. With Sutton in England and Berthault in France, *S. commersoni* and other species remained constant over a several-year period; even the modifications produced through sexual reproduction did not lead to anything approaching the *tuberosum* type. Berthault concluded that *S. tuberosum* is distinctly different in its floral characters from all the wild species, particularly in its rotate corolla and sharp-pointed calyx. Since the *tuberosum* type was grown in more or less its present form in South America, before its discovery by white men, the cultivated potato may be a distinct species

the wild progenitor of which has disappeared. Another theory is that *S. tuberosum* arose from a cross between some of the wild species or from mutations in prehistoric times. Various wild species have been successfully crossed with each other and with *S. tuberosum*. The name *Solanum tuberosum* was applied by the pre-Linnaen botanist, Kaspar Bauhin, in 1596.

History.—The tuberous *Solanums* are native to America, being found, from Colorado to southern Chile, in elevated regions having a temperate climate. The wild form belonging to the southwestern United States is *S. fendleri*. The cultivated type was found by the Spaniards in Peru in the sixteenth century and was taken to Europe by them. The name "batatas" was applied, because of a supposed resemblance to the sweet potato, which was discovered previously and so called. According to some historians, potatoes were introduced to England from Virginia by Sir Francis Drake or Sir Walter Raleigh in about 1580. Since the potato was not native to the eastern United States, some writers have supposed that the plant taken from Virginia to England by the early voyagers was either the Openauk, or Indian potato, a tuber-forming legume native to Virginia, or the Jerusalem artichoke, also a native of Virginia. The various accounts of the introduction and development of potatoes in Europe have been reviewed by Safford (1925). The first published record was that of Pedro de Cieza de Leon, who, in 1538, found potatoes in the upper Cauco Valley of Colombia and, later, at Quito, in Ecuador, and in Peru. In this region, in altitudes too high for corn culture, potatoes were and still are one of the chief foods of the people. They were cultivated also by the natives of southern Chili, in regions of low altitude near the coast. Just when they were taken to Europe is uncertain, but they were being grown in Italy in 1585. The first illustration of the potato plant is a colored drawing published in 1588 by Clusius, a botanist of Vienna. Foliage, flower, and tuber characteristics have apparently changed little in the 350 years since.

In most countries, the potato was regarded with ill favor as a food, until failure of other crops forced the people to eat it. Although its culture as a food crop was urged in England in 1663, it required over 100 years for this cultivation to become general. In Ireland, it early became an important food crop. Probably this is why the term "Irish" potato is now used in English-speaking countries. In Germany, in 1744, Frederick the Great compelled the people to grow potatoes, but he could not make them eat potatoes, until a famine came to his aid. This crop was first grown in the United States, in 1719, by a Scotch-Irish colony in New Hampshire. Gradually, it became an important crop in the North. Many American varieties are descendents of a comparatively recent introduction—the Rough Purple Chili. This variety, introduced from Panama, in 1852, by the Rev. Chauncey Goodrich, of Utica, New York,

has, through its seedlings, produced many other varieties. Still others have been introduced from England. In general, each country has developed its own locally adapted varieties.

Plant Characteristics

The plant is a herbaceous annual, propagated by sexually formed seeds or by the tubers. The aerial stems become procumbent and have several axillary branches. The stems are round or angular, pubescent or glabrous, green or more or less purple. The first leaf on the stem is usually simple, and the later ones, pinnate, with three or four pairs of large, entire, petioled leaflets and smaller ones between. The leaflets are broad and smooth under cool, humid conditions but become narrow and somewhat troughlike under extreme heat and dryness. The leaves are arranged on the stem in a spiral. Plants grown from tubers do not have a tap-root. The fibrous roots are small. They arise in groups of three, just above the nodes on the underground part of the stem. They may extend to a depth of 3 to 4 feet and nearly as far horizontally. Thus, Musgrave (1926) finds some competition between the plants in rows 34 inches apart. As most of the roots are comparatively near the surface, the potato does not seem adapted to culture without irrigation or frequent rainfall. According to Hosans, the ratio of the weight of roots to tops is only 1:44, whereas in most plants, it is about 1:10.

Flower.—The cymose inflorescences occur in the axil of every sixth node. The flowers open progressively over a period of several days. The rotate corolla is five-lobed and white, yellow, purple, blue, or striped, according to the variety. The five stamens are borne on the corolla tube and converge around the pistil. They bear large, erect anthers, which dehisce by a terminal pore. There are two carpels, forming the two-loculed ovary, with a single style. Each cell has one axile placenta. The fruit, or seed ball, is a green, round berry about ½ inch in diameter and generally contains numerous seeds, though sometimes seedless fruits are produced. Seed balls are produced only rarely in most regions. The seeds are very small, kidney shaped, and smooth; they are embedded in the pulp of the fruit.

Pollination.—The flowers produce no nectar and are rarely visited by insects. According to Müller (1923), however, bumblebees do visit them and carry pollen. Müller studied pollination in a variety which set fruit from 15 per cent of unenclosed flowers. When covered with parchment bags, 5 per cent set; when emasculated and left uncovered, 2 per cent set; hence, wind and insect-pollination play a minor role. Varieties which do not produce viable pollen yet have normal ovules seldom set fruit, a fact which indicates the rarity of cross-pollination. Since a good set is not obtained under bags, Müller isolated the flowers

by slipping a small cylinder of straw over the pistil and plugging the upper end with cotton. According to East (1907), the stigma is most receptive the second day the flowers are open. The anthers dehisce when the flower is fully expanded. To obtain pollen for pollination work, it is necessary to split the anthers, since little pollen is discharged.

Sterility.—Various degrees of sterility exist in the potato. Failure to blossom is the most pronounced type; yet among 671 varieties, East found only 31 which showed no signs of flowering, and of these, 26 are reported to have flowered elsewhere. He found that 40 per cent of the named varieties shed their buds before flowering. In a lot of 2-year-old seedlings, there was about the same ratio of flowering to non-flowering individuals. This discredits the view held by some, that non-flowering in the potato is due to senility arising from long-continued vegetative propagation. Broili (1919) reports that girdling, or binding the stems with wire, leads to fruit setting. Another theory, advanced many years ago by Knight and by DeVries, is that non-fruiting is due to the development of the tubers. Young (1922), however, found in the McCormick variety a positive correlation between vegetative growth and tuber production, vegetative growth and seed production, and tuber and seed production. Conditions favoring one character favor the others, and there is no mutual antagonism between them. East (1908) repeated Knight's experiment on removal of tubers from the developing plant but found no effect upon viability of pollen or upon fruit setting. With reference to sterility, he makes the following classes:

1. Varieties whose buds fall without opening.
2. Varieties in which a few flowers open but fall at once.
3. Varieties in which flowers persist several days but lack viable pollen.
4. Varieties which flower freely, produce viable pollen, and bear fruits.

Failure to flower is due largely to environmental factors; it varies, in any one variety, with seasonal and climatic conditions. Probably all varieties would flower under proper environmental conditions. Production of non-functional pollen, on the other hand, is due to the genetic constitution of the variety and is little altered by environmental factors. Some varieties produce both viable and non-viable pollen. East states that the latter is shriveled and irregular. Some of the good pollen grains are round, others have one to five light protuberances. The latter germinate, and their tubes grew more rapidly, in 7 per cent sucrose. Impotent pollen results from degeneration after the liberation of the microspore from the tetrads; the presence of such pollen does not affect normal flowering.

Degeneration of the ovules and embryo sac may occur, also. Young (1923) found that this is caused by environmental conditions; it may

happen at any stage of development and is probably one of the direct causes of premature floral abscission. Dorsey (1919) shows that in the dropping of buds or flowers, the abscission zone of the pedicel generally develops and causes the abscission of bud or flower before pollination and fertilization occur. This phenomenon may be an effect of unfavorable environment, independent of pollen or ovule degeneration. The sterilities of American varieties have been extensively investigated by Stout and Clark (1924), in northern Maine, where premature abscission is rare and most varieties flower freely. When pollinated with viable pollen, most varieties produced seed balls under these favorable conditions. As elsewhere, many of the cultivated varieties were male-sterile, producing no viable pollen, while others produced a variable amount of abortive pollen. Male sterility was found also in crosses between wild species.

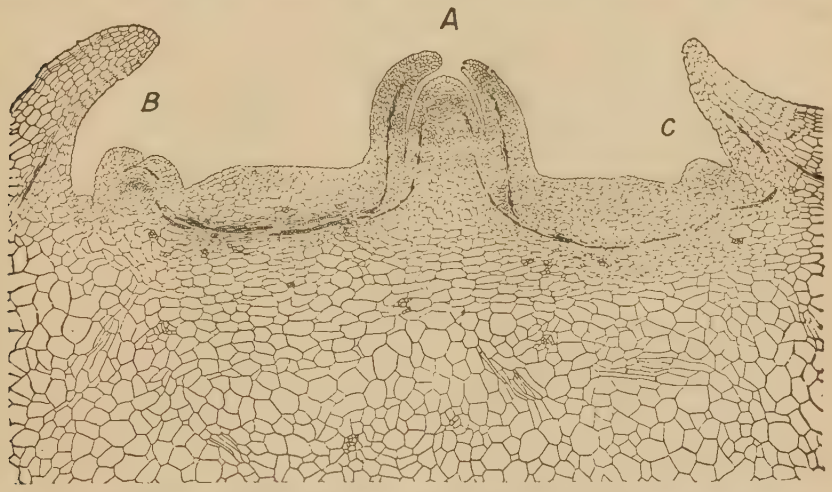

FIG. 55.—General view of a section through a potato "eye." A. Central or apical bud. B, C. Lateral buds. (*After Artschwager.*)

Self-sterility, due to incompatibility, was not found in cultivated varieties or seedlings but does occur in some wild species.

Stolons and Tubers.—The leaves on the underground part of the stem are small and scalelike; in their axils, lateral stems called "stolons" arise. These are of variable length, more or less fleshy, and of typical stem structure. The tubers are swellings arising at the end of these stolons. The tuber is a shortened, thickened, underground stem, with scalelike leaves, or leaf scars, subtending the "eyes." The eye, in its entity, is a leaf scar with its subtended axil, which contains a lateral branch and the latter's axillary buds and undeveloped internodes. Because of short internodes, the nodes are brought close together, and the buds lie in nearly the same plane. Since there are several buds on

each of these shortened branches, it is possible to get several shoots from an eye. The central bud in an eye is the terminal bud of the branch and develops first upon renewal of growth. There is also a correlation between the development of different eyes on the tuber. Sprouts usually develop first from eyes at the apical or the distal end of the tuber; this development is known as "apical dominance." Appleman (1918) showed that when the vascular connection between different eyes was severed by cutting the tuber into pieces or by notching around the eyes, apical dominance disappeared and all eyes developed at about the same rate. Apical dominance within the tuber and within the individual eyes disappears when the first sprouts are destroyed or are checked in their growth.

The epidermis of the tuber sloughs off in the early stages of development and is replaced with a periderm, six to ten cells thick. The periderm consists of small, flat cells, which become suberized during the ripening of the tuber or upon exposure to dry air. Thus, a tough skin is formed, which protects the tuber against bruising. It is fairly impermeable to gases. Lenticels take the place of stomata. Below the periderm is a rather dense layer of cortex, which is variable in width and consists of small parenchyma cells, densely filled with starch grains. The vascular bundles approach the surface of the tuber at the eyes, connecting the developing buds and reserve materials in the tuber. The vascular tissue of the tuber is a continuation of that of the stolon. It is of only slightly greater extent in the tuber than in the stolon but is more scattered, only individual groups here and there being united by interfascicular cambiums. The xylem is mostly primary, excepting in the larger groups where secondary xylem is present. During tuber growth, the phloem becomes more and more broken up into small strands, which become scattered throughout the cortex and pith. The pith, enclosed by the vascular ring, constitutes the greater portion of the tuber. It may be divided into the more dense portion—the outer medulla—and the less dense portion—the inner medulla. The pith consists of large parenchyma cells less densely filled with starch and other contents than is the cortex.

Tuberization and Tuber Development.—Tuberization is the initiation of tuber development, the stolon stops elongating and begins to thicken at the tip. Tuberization has been determined by Clark (1921) to occur normally at about the time the buds of the first inflorescence are formed, usually 3 or 4 weeks after the plants appear above ground. Furthermore, he finds that, in general, tuberization of all stolons on the plant occurs at about the same time. The large and small tubers found at harvest result from an unequal growth rate, not from different ages.

The anatomical aspects of tuberization have been studied by Artschwager (1918). The first change in the tip of the stolon is extensive cell

division in the pith and, to a lesser extent, in the cortex. This results in a swelling of the stolon, which becomes oval. Expansion of the pith causes the vascular tissue to bend outward. The tubers grow both in length and in thickness. Proliferation of the parenchyma cells of the outer medullary zone and, to some extent, of those of the cortex, contributes most to tuber growth. Sieve tubes traverse the regions of

FIG. 56.—Section through the eye of an immature tuber, about 15 mm. in diameter. (*Drawn by Charles P. Dutt, University of California.*)

active growth in all directions. An accumulation of starch appears in the stolons even before tuberization (Rosa, 1926), and this is the only region of the plant in which starch is ordinarily deposited in any quantity.

The cause of tuberization is unknown; it is simply a characteristic of the potato plant to form tubers under certain conditions and at a definite stage of growth. Bernard (1902) and Magrou (1921) have endeavored to prove that tuberization is due to the action of an endophytic fungus,

which exists in symbiotic relation with the roots. The fact that it is the roots and not the stolons which are invaded and that potatoes form tubers in water cultures and other sterile media indicates that endophytic fungi do not play a primary role in tuberization. Moreover, while Jones (1924) found the endophytic fungus of Bernard widely distributed in roots of peas and of other plants in the United States, he found it in potatoes in only one instance. After Laurent had shown that tuberization occurred in sterile sugar solution, Bernard (1902) enlarged his theory, as follows:

> The state of hypertrophy—which we call tuberization—may be induced by various agents which bring the cells into contact with substances of relatively high osmotic pressure. Among these substances in nature the products of fungus activity are most important.

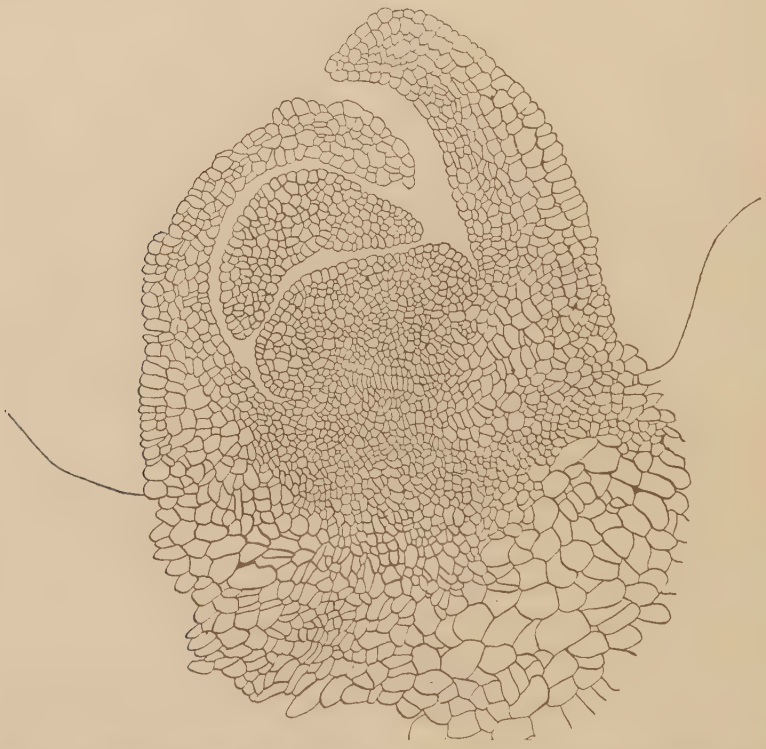

FIG. 57.—Section through the central sprout of the apical eye on a mature dormant tuber. This shows the sprout to be already formed at the beginning of the dormant period. (*Drawn by Charles P. Dutt.*)

On the other hand, Lutman (1919) finds that the osmotic concentration of the juice of young plants is highest in stalks and leaves; it is always low in the tubers, while during the period of tuber formation, it is highest in the aerial stems.

Tuber development is much affected by environmental factors. It is favored by darkness and checked by light, though light indirectly favors tuber growth through the synthesis of food in the leaves. Underground branches form tubers; those aboveground, vegetative shoots. Vochting (1887) showed that tubers might form in the tops of plants, if

FIG. 58.—Section through the apical eye of a mature tuber 71 days after harvest. (*Drawn by Charles P. Dutt.*)

light were excluded. That the daily light duration also exerts an important influence is shown by Garner and Allard (1923) in table 58.

Disregarding the 5-hour day, which is too short for normal development, the ratio of tubers to tops increases with the shorter days. A long day favors vegetative growth chiefly and retards development of tubers and flowers. The 10-hour day favors tuberization, but since carbon

TABLE 58.—EFFECT OF LENGTH OF DAY ON TUBER DEVELOPMENT, MCCORMICK VARIETY, WASHINGTON, DISTRICT OF COLUMBIA
(*Garner and Allard*)

	Height of plant, inches	Weight of tubers, grams	Average weight of dry tops, grams	Ratio, tubers to tops	Condition of tops, Aug. 28
Five-hour day	20	80	2.8	29:1	Dead
Ten-hour day	12	320	1.9	168:1	Mostly dead
Thirteen-hour day	25	664	30.9	22:1	Green
Full day, 16 hour	32	471	32.0	15:1	Green

FIG. 59.—Longitudinal section through the tip of a stolon, before thickening begins. (*Drawn by Charles P. Dutt.*)

synthesis is limited, the actual weight of tuber is decreased. We have here an explanation of the extremely rapid development of tubers during the short days of autumn. In northern regions, where potatoes thrive best, the long days of summer favor extensive vegetative growth, followed by a period of rapid tuber development during the autumn. Carbohydrate accumulation is essential for tuber growth; this accumulation results from an excess of manufacture over utilization. The surplus may be due not to increased manufacture but to decreased ability of the

plant to utilize the carbohydrate. Carbohydrate storage is then correlated with loss of power to utilize it in vegetative development. Adams (1923) found that potato varieties may differ in their response to length of day, however.

FIG. 60.—Section through tip of stolon in the initial stage of tuberization. Thickening of the pith parenchyma has begun, but little swelling is yet apparent to the eye. (*Drawn by Charles P. Dutt.*)

Low temperatures favor tuber development. Bushnell (1925) discovered that at high temperatures (26 and 29°C.) the carbohydrate available for translocation is reduced, because of the high rate of respiration; and this roughly corresponds to the reduction of tuber growth. At 29°C. no tubers formed. Hardenburg (1923) found that more tubers formed at 20 than at 15°C. but that total production and average weight

of tubers were much greater at the lower temperature. At 20°C. there were more stolons, and these were much branched, with small side tubers.

Clark (1921), in Colorado, found that time of first irrigation had considerable influence on the number of tubers per plant. When irrigation

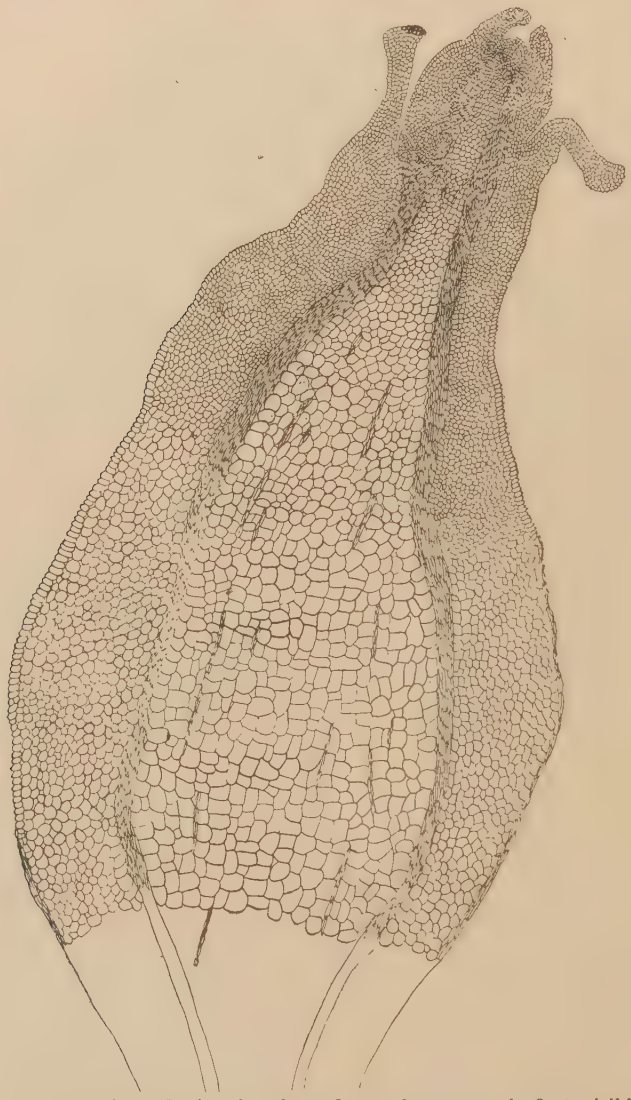

FIG. 61.—Section through tip of stolon when enlargement is first visible. Note the proliferation of the pith, and the scattered strands of phloem. (*Drawn by Charles P. Dutt.*)

began before tuberization, there were 6.6; when irrigation was deferred until after tuber setting, there were 4.8 tubers per plant. Frequency of irrigation after tuber setting did not affect the number but did influence

the size of the tubers. Soil type was also found by Clark to have a marked influence on number and size of tubers per plant, as shown in the following table:

	Variety, Triumph		Variety, Rural New Yorker	
	Average number	Average weight	Average number	Average weight
Heavy clay	3.1	62.0	3.0	125.3
Clay loam	4.2	93.3	4.9	136.5
Fine sandy loam	5.9	83.3	6.3	162.8

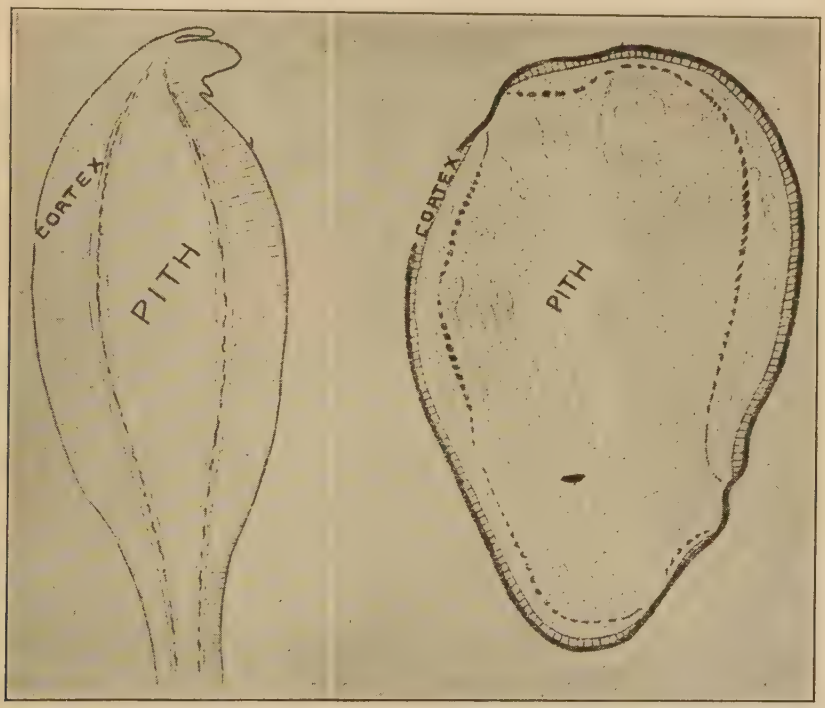

FIG. 62.—Diagrams of swollen stolon tip and of mature tuber, showing the homologous parts of these organs. (*After Artschwager.*)

Hardenburg obtained similar results in New York and, in addition, found that on muck soil, the set was twice that on sandy loam.

Hardenburg found that when the moisture content of the soil was raised from 17 to 23 per cent, the number of tubers increased, at 15°C.; but at 20°C. the opposite relation was found. Time of planting may affect tuberization. He found that in plantings extending from May 31 to July 10, the average number of tubers decreased with the later plant-

ings. Such factors as time of planting depend for their effect upon the interaction of several environmental influences, which may give different results, depending upon the variety and the locality.

Climatic and Soil Requirements

In general, relatively cool conditions are most favorable for tuber and plant development. Bushnell (1925) concludes that the optimum temperature for tuber production lies between 16 and 18°C. Potato culture is most successful in the northern tier of states, but good crops of early varieties are grown also in the South in the spring and fall. Smith (1915) analyzed the relation of weather to yield of potatoes. He found that the regions north of the isotherm of 21°C. for July produce higher yields than the warmer regions to the south of this isotherm.

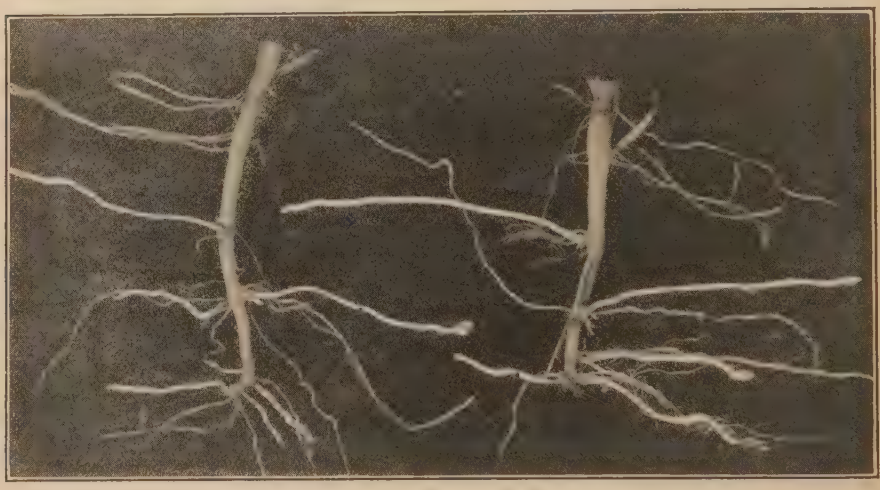

Fig. 63.—The underground portion of potato plants when the stolons are in the initial stages of tuberization. The lower stolons are shorter than those above. The uppermost stolons on both plants have turned into vegetative shoots.

Soil temperature is important, also. Probably one of the chief advantages of peat and muck soil for potatoes is the relatively low temperature a few inches below the surface. In Nebraska, Emerson (1914) found that a straw mulch lowered the soil temperature around the tubers several degrees and gave larger yields than did soil unmulched.

Rainfall and humidity are likewise important in determining potato yields, especially through their influence upon diseases. Other conditions being equal, the relative humidity of the air is probably a minor factor, as the plants thrive as well in the dry air of the western states as in the humid conditions of the East. Seasons of above-normal precipitation are often accompanied by epidemics of late blight and other fungus

diseases. Smith (1915) found no very significant correlation between rainfall and yield of potatoes in Ohio, temperature being the dominating factor.

FIG. 64.—The underground portion of potato plants a few days after tuberization was initiated.

FIG. 65.—The underground part of a potato plant, planted at Davis, California on May 17 and harvested August 10. Note the unusual growth of the stolons and the failure to develop tubers, under high temperature conditions.

Soil type is important in determining the shape and smoothness of tubers. In light, well-aerated soils, they are smooth and of the typical varietal shape. Sandy loams and peat soils are most used for potatoes.

Willaman and West (1924) did not find any marked relation between soil type and composition of the tubers, though loam soils seemed to produce the highest content of dry matter, N, and ether extract. Contrary to the common idea, sandy soils gave the lowest per cent of dry matter. No correlation was found between specific gravity and either N or carbohydrate content; a tuber high in dry matter may or may not be high in starch. It is generally believed, however, that high starch and low water content go hand in hand. In Colorado, Headon (1924) found that heavy applications of sodium nitrate did not materially alter the content of dry matter, fiber, sugar, or starch but did increase the percentage of some of the nitrogenous constituents. Miss Goldthwaite (1925) studied the composition and cooking quality of irrigated *vs.* non-

FIG. 66.—The formation of axillary tubers (B) and the transformation of the stolon into a vegetative shoot (D) which occurs in some varieties when subjected to high temperatures late in the growing season. The tubers are also forming vegetative shoots (C).

irrigated potatoes in Colorado. She concluded that there was no relation between the moisture content of the potatoes and the amount of water which they received during the growing season. She found that the percentage of starch was slightly lower in dry-land potatoes than in those grown with irrigation but that the former were richer in nitrogenous matter and in ash. The dry-land potatoes were considered best in flavor and cooking quality.

CULTURAL CONSIDERATIONS

Seed Potatoes

The term "seed" is commonly used to designate tubers for planting. Whole tubers or cut pieces used for planting are also called "sets." It is generally recognized that yield depends to a large extent upon the nature

of the seed planted. There has been an enormous amount of investigation upon the subject, often with apparently conflicting results. Questions are involved relating to quality of the seed tubers and to preparation of the sets for planting. Some of the principal factors concerned are (1) the source, in relation to vigor and disease infection, (2) tuber shape and type, (3) time and method cutting, (4) size of tuber, (5) size of set, (6) effect of greening and sprouting, (7) maturity, and (8) degree of dormancy.

Source.—Growers in the South Atlantic states secure their seed potatoes from Maine and the maritime provinces of Canada; the Gulf states import seed from the north central states. Environmental condi-

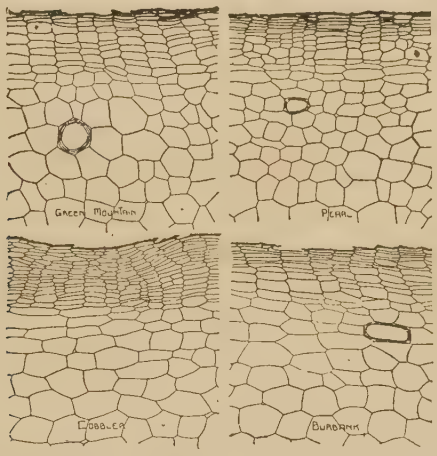

FIG. 67.—Sections through the periderm of mature tubers in 4 varieties of potatoes. Cobbler has a thicker and more dense periderm than Green Mountain which may be associated with the longer rest period in the former. (*After Artschwager.*)

tions in the North are thought to be conducive to the production of healthier and more vigorous seed than are regions farther south. The time between harvest and planting is long in the South, so that the natural rest period of southern-grown tubers is over long before planting time. Conditions there favor also the more rapid spread of degeneration diseases than do conditions in the North. By growing healthy stock for 1 year in northern and southern Maine, Long Island, and eastern Virginia, then testing the progeny from each source in Maine the following year, Schultz and Folsom (1925) found that the farther south the potatoes were grown, the greater the percentage of diseased plants. Spindle tuber and mosaic increased more in Virginia and Long Island than in Maine, and rugose mosaic was contracted in Virginia, no doubt from weeds. These and similar diseases are probably the cause of the apparent degeneration of potatoes grown continuously in the South. Numerous experiments have shown

northern seed to be generally more productive in the South than locally grown spring-crop potatoes.

On the other hand, potatoes grown in the South as a fall crop are often equal or superior to northern seed. Second-crop potatoes grown in New Jersey, Virginia, Missouri, and California have been proved to be satisfactory for use as seed in most cases though somewhat later in maturing than northern seed. Furthermore, potatoes grown as a summer crop in the cool uplands of western Maryland and North Carolina, as well as of California, prove satisfactory for seed. An experiment by Martin, *et al.* (1925), for a 3-year period, compared seed grown in Maine and in southern New Jersey as a fall crop, using the same strains throughout. The progenies were compared in both states each year. Two varieties, Irish Cobbler and Green Mountain, were used. The former has a long rest period, and the seed from New Jersey was 3 to 5 days slower in germinating than that from Maine, with a corresponding difference in flowering date and even greater difference in time of maturity. In the Green Mountain variety, there was no difference in growth period or time of maturity in seed from the two sources. Tubers produced in New Jersey were smaller and more immature than those grown in Maine, thus introducing a possible cause for differences in comparing seed from the two sources. The Maine seed produced more stems per plant, but this advantage was offset by a greater percentage of diseased plants. There was no significant difference in yield between Maine and New Jersey seed.

The fact that northern regions produce better seed because of lower temperatures is a common belief. Werner (1925) states that high soil temperature alters the shape of the tubers, causing them to become more elongated, but that this does not necessarily affect the seed value. He grew potatoes under controlled temperatures ranging from 13 to 29°C.; he found that the tuber yield was much reduced at the higher temperatures but that there was little difference in their producing capacity the following seasons. In the field, however, high temperatures lower seed quality, because they mask certain virus diseases. These diseases, going unnoticed, spread to adjoining plants and result in an increased amount of disease the following year. Werner (1925) showed that potatoes grown under irrigation are often inferior for seed to those grown without irrigation. Under dry-farming conditions, opportunities for spread of disease are less favorable, and there may be some elimination of diseased individuals. Some lots of irrigated seed, however, are of good quality. Werner concluded that the apparent degeneration under irrigation was due to the rapid spread of disease, especially spindle tuber. When disease was eliminated by caging healthy plants to prevent their infection by insects, irrigated seed yielded as well as non-irrigated.

Tuber Type.—Krantz (1923) found, in the Early Ohio variety, that knobs, cracks, swollen lenticels, deep eyes, prominent eyebrows, and, to

some extent, color of tuber vary according to the environment under which the tubers developed. These characteristics are not influenced by selection or by the type of the seed planted and do not detract from the value of the tubers for seed. Furthermore, Krantz found no correlation between tuber form and yield when oval, flat, short, elongated, and cylindrical lots of the same variety were compared. Salaman (1922) found that second-growth knobs, or rough tubers, produced considerably larger crops than sets from smooth tubers. There was no correlation between knobs on the seed tubers and the occurrence of second growth in the resultant crop.

FIG. 68.—Distortion in tuber shape is shown in A and B, as a result of high temperature the latter part of the growing season. C. shows the normal for the variety. All tubers are of equal value for seed.

Hardenburg (1925) found no consistent effect upon productivity of potatoes grown on different soils, except that, in two instances, muck-land seed germinated earlier and yielded more heavily than seed from mineral soils. Seed grown in sandy-loam soil showed little consistent gain over that grown in heavy loam. The common prejudice against muck-land potatoes and the preference usually held for seed grown on sandy land do not seem to be justified.

Size of Tuber.—When tubers are planted whole, the yields increase with the size. In the United States, the amount of seed used per acre is determined by economic considerations, and large tubers cannot be planted whole. Hence, the question of size of tuber resolves itself into a comparison of small tubers planted whole with cut sets of large tubers.

Clark (1921), in a 3-year experiment in Colorado (Table 59) shows that whole sets are more productive than cut sets of the same weight.

TABLE 59.—YIELD PRODUCED BY WHOLE *vs.* CUT SETS OF SAME SIZE (*Clark*, 1921)

Type of sets	One-ounce sets		Two-ounce sets	
	Average number of stalks	Bushels per acre marketable	Average number of stalks	Bushels per acre marketable
Whole tubers	1.8	250	2.6	288
Halves	1.8	241	2.5	254
Quarters	1.6	224	2.0	249

To eliminate the error involved in the mass selection of seed tubers of different sizes, Stewart (1922) tested small whole tubers against cut sets of the large tubers from the same plants. His results were as follows: (1) Yield from small whole tubers exceeded that from cut seed by about 3.5 per cent; (2) a better stand was produced by whole sets; (3) rate of plant growth was more rapid from whole sets; (4) average number of stalks per plant was 1.91 from whole sets and 2.14 from cut sets. The latter result opposes the usual idea that whole sets produce an excessive number of stalks simply because they have more eyes than cut sets. Whole sets, planted a considerable time after the end of their natural rest period, however, generally do produce a much larger number of stalks than do cut sets (Rosa, 1922). Small tubers have been opposed because of the supposition that they are mostly from diseased plants; hence, would produce diseased progeny. But Stewart found actually a higher per cent of leaf roll in plants from cut seed (probably because of inoculation of the sets with the cutting knife). Moreover, Folsom, *et al.* (1926), find that in general, there is no correlation between size of tuber and infection with virus diseases. Whole sets often produce a greater number of stems, sprout more slowly, give a better stand, and produce a higher total yield but a greater percentage of small potatoes than do cut sets. The use of small tubers for planting has long been established in England, and obvious economy as well as other possible advantages should lead to their use in America. Since small to medium-sized tubers are also more economically cut for planting, with less waste from "blind pieces," crops intended for seed purposes should be handled so as to produce a large proportion of the smaller sizes. Large sets and thick planting accomplish this.

Size of Cut Sets.—The amount of seed used per acre is determined by (*a*) size of set, (*b*) space between rows, and (*c*) space in the row. Appleman (1918) showed that size and vigor of the plant depend upon the size of the set, *i.e.*, upon the amount of tissue surrounding the growing bud.

If the size of set falls below a certain minimum, the sprouts are weak and slender and remain so throughout the season, with resultant low yield. The large set furnishes something to the plant arising from it, which is not present in sufficient amount in the smaller set. The analyses of Ramsey and Robinson (1917) show that carbohydrate, N, and ash constituents of the mother set are far from exhausted, even at the end of the growing season. Numerous experiments show that, under equal conditions, yield increases with the size of set planted, though the rate of increase follows the law of diminishing returns. Increased size of set is nearly always accompanied by an increased number of stalks; since the number of tubers formed per stalk tends to be constant under uniform conditions (Rosa, 1922), the increase in number of stalks leads to an increase in number of tubers. The net increase in marketable potatoes seldom increases beyond sets 2 ounces in weight.

TABLE 60.—EFFECT OF SIZE OF CUT SETS UPON PRODUCTION, WHERE PLANTING DISTANCE IS CONSTANT, IN BUSHELS PER ACRE
(*Werner*, 1919)

Size of set	Amount of seed per acre	Total yield	Yield of U. S. grade No. 1 tubers	Average number of stalks	Net yield marketable
½ ounce	6.5	197	184	1.2	178
1 ounce	15.0	239	204	1.8	224
2 ounces	30.0	264	233	2.7	234
4 ounces	60.0	298	252	4.3	238

Experiments indicate that the most profitable way to use a large amount of seed per acre is by close planting, not by the use of abnormally large sets. The effect of the amount of seed per acre, when size of set is constant and planting distance is varied, is shown in Table 61.

TABLE 61.—EFFECT UPON YIELD, OF PLANTING SETS OF CONSTANT WEIGHT (1 OUNCE) AT DIFFERENT SPACINGS. YIELDS IN BUSHELS PER ACRE OF U. S. GRADE NO. 1 TUBERS
(*Werner*, 1919)

Space between rows, feet	Space in row, inches						
	6	9	12	15	18	21	24
2	295	289	280	273	267	195	195
2½	273	249	221	218	224	180	172
3	256	238	229	223	193	192	208
3½	219	208	196	192	211	208	191

In general, yield increases with closeness of planting. The most profitable yield is not always the largest, however. The cost of seed at planting time largely determines the amount per acre that may be planted profitably. On fertile soil and under favorable growing conditions, close planting is advisable. The average amount of seed planted per acre in the United States is about 8 bushels; this might generally be doubled to advantage, and under the most favorable circumstances, 30 to 40 bushels per acre may be used profitably.

Greening and Sprouting.—Tubers which have reached the end of the rest period, when spread in a thin layer in a warm, light place, develop chlorophyll in the cortex, and short, stout sprouts arise from the eyes. If kept in the dark, the sprouts become long and slender and are broken off in preparation for planting. Many claims have been made as to the superiority of greened sprouted sets for planting. Experimental results in the United States, however, do not show much advantage, in yield or in earliness, from their use. For a seed plot, preliminary sprouting may be advisable; Appleman (1924) shows that presumably diseased tubers produce weak sprouts and that these may be used as an index for the elimination of undesirable tubers.

Where seed potatoes have to be kept for some time after the end of their dormant period, it may be best to prevent sprouting by holding them at low temperatures. Appleman (1924), however, found no decrease in yield when the seed tubers had been de-sprouted one, two, three or four times, in comparison to seed held dormant in cold storage. The same worker found that in tubers allowed to sprout in storage, the sprouts being removed at intervals, the number of sprouts increased with each succeeding crop. After the eighth or ninth crop of sprouts had been removed, there was a general outburst of sprouts all over the tuber. Following this, there were no more sprouts, but small, secondary tubers arose from the eyes. Apparently, this secondary tuberization, or blind sprouting, which often occurs in the field, may also result from long storage at rather high temperature. Something essential for sprout growth has been exhausted. In the foregoing experiment, the first and second crops of sprouts were most vigorous, but the vigor of succeeding crops remained about constant until the final outburst of small sprouts.

Seed Maturity.—Tubers harvested immature may be more productive as seed than tubers fully matured before harvesting. Table 62 illustrates the decrease in yield, which may accompany increasing maturity of the seed tubers.

Immature tubers, being smaller, upon cutting, give sets with more eyes than do sets of the same size from large tubers. This may result in plants with more stalks and greater tuber production. Harvesting immature also allows less opportunity for the tubers to become infected with virus diseases. Physiological differences which may exist between

TABLE 62.—EFFECT OF SEED MATURITY UPON PRODUCTIVITY
(*Martin*, 1921)

Stage of harvesting seed crop	Yield of seed crop, bushels per acre	Yield following year, bushels per acre
Dug 2 weeks after blooming	125	271
Dug 2 weeks later, still green	157	260
Dug when 24 per cent of leaves were dead	207	250
Dug when 50 per cent of leaves were dead	258	243
Dug when 92 per cent of leaves were dead	281	216
Dug when 100 per cent of leaves were dead	281	196

mature and immature seed were found by Appleman and Miller (1926) to disappear during the storage period. Potatoes harvested at intervals through the growing season were very different in chemical composition. The maturation process, however, continues during storage, and by the end of the rest period, potatoes dug immature have almost the same composition and respiratory response as potatoes fully matured upon the plant.

Dormancy.—Normally matured tubers have a natural rest period of 1 to 3 months, during which sprouts do not form even when planted under conditions favorable for growth. This fact is shown by Appleman (1914) to be associated with the thickening of the periderm, which retards the rate of entrance of O_2 into the tuber. Oxygen is essential for some processes necessary to growth renewal. Emergence from the rest period is gradual; tubers of certain varieties may sprout slowly 2 months after harvesting, but they will sprout much more rapidly after 4 or 5 months. Accompanying emergence from the rest period is a progressive increase in the number of sprouts which will arise from a tuber or cut set. At first, only one sprout will be formed—the condition of apical dominance. This condition is followed by a period where several sprouts will arise simultaneously—the multiple-sprout stage. The more advanced the rest period, the greater the number of stalks arising from each set.

In all questions on source of seed, size of set, whole *vs.* cut sets, seed maturity, and storage conditions for seed potatoes, the stage of the rest period at planting time needs to be considered. Some of these relations have already been discussed. Potatoes will not sprout at temperatures favorable for growth during the rest period. Following this period, temperatures below 5°C. are required to inhibit sprouting completely. The natural rest period is not greatly prolonged by cold storage—there is only an enforced dormancy. Even after 2 years in cold storage, potatoes will form normal sprouts, though they are not very vigorous.

The chemical changes occurring in the rest period and determining the time and rate of growth renewal are unknown. Carbohydrate

balance, especially the starch-to-sugar change, proportion of different forms of N, changes in form of P and of diastase, oxidase, and proteolytic enzymes, have been shown by Appleman to be unrelated to emergence from the rest period. The activity of catalase increases at the time of sprouting but is more likely a result than a cause.

The dormancy of potato tubers offers a difficulty in the use of spring-crop potatoes for planting a second, or fall, crop, for only about 1 month intervenes between harvesting and planting. Appleman (1914) showed that removal of the periderm resulted in prompt sprouting, if suberization of the cut surface was prevented; young tubers whose surface was not corked at all would sprout promptly under conditions of moisture and abundant O_2 supply. Cutting near the eye, greening by exposure to subdued light, treatment with hydrogen peroxide and with ethyl bromide, were all found by Appleman to hasten sprouting. These treatments, except perhaps the last, permit an increase of the O_2 supply to the tissues within the tuber. Rosa (1923) found that treatment of cut sets in solutions of nitrates, permanganates, and other oxidizing agents resulted in more rapid growth. Denny (1926) reports striking stimulation of growth by treatment of dormant tubers with ethylene chlorhydrin, ethylene dichloride, potassium thiocyanate, and other compounds. The mode of action of these treatments has not yet been explained; it may be due to alterations in the permeability of the tissues, whereby gas exchange is promoted. At present, the most practical treatment for breaking the dormancy of tubers, in preparation for planting, seems to be to expose them to the fumes of ethylene chlorhydrin for 24 hours. One half to one cubic centimeter of the 40 per cent aqueous solution is used per liter of space in the chamber. An advantage of this treatment is that the stimulating effects persist if the tubers are treated several days before cutting for planting. Some difference in the response of various varieties to stimulants is reported by Denny. Less time or lower concentration has to be employed as the tubers approach the end of their rest period.

Nutrition and Manuring

Because of difficulty in growing potato plants in nutrient solutions, little work has been reported on solution cultures. Newton (1923) has devised methods for this, however. He found that a supply of Ca, additional to that in the set, was necessary for early stages of plant growth. Solutions lacking K gave darker-green foliage, a longer growing period, higher dry-matter content, and larger tuber production than complete nutrient solution gave. The most significant depression in growth and tuber production occurred in solutions lacking P. The large amount of K and the low content of P and Ca usually found in the tuber are in line with these results. In sand-culture experiments, Johnston (1925) found that best growth (of the vegetative parts) is associated with high N in the

nutrient solution, except where the nitrate is supplied in a Mg. salt. Magnesium is usually toxic to potatoes, possibly through limitation of the Ca supply. Martin and Shive (1921) find that, in general, high yields of both tops and tubers were associated with intermediate proportions of the two salts—calcium nitrate and magnesium sulfate. The proportions producing high yield of tops are said by these workers to be more definitely defined than those which produce high yields of tubers. The results of such studies cannot be interpreted directly in terms of field practice, but they do indicate the real requirements of the potato plant.

Many field experiments have been conducted to determine the nutrient requirements of potatoes. Such experiments are useful in that they indicate the proper treatment of the particular soil on which the tests are performed. Their interpretation in terms of general practice is limited by the wide variations in chemical composition of different soils. Some of the work which may have more than local application is discussed below.

Source of Potash.—Because the potato removes a larger amount of K from the soil than do many other plants, especial importance has been attached to this element in potato manuring. Experiments in several eastern states, however, have shown that not more than 5 per cent potash is profitable, where as much as 1,500 pounds per acre of a "complete fertilizer" is applied. In fact, decreased yields and retarded maturity sometimes result from larger amounts of potash. Kainit (a mixture of K, Mg, and Na sulfa es and chlorides) is often found to be somewhat toxic to potatoes. Comparisons of chloride and sulfate of potash have given rather contradictory results. Zimmerley (1925) reports an experiment where these salts were applied annually for 14 years, at two rates. Three crops of potatoes were grown the latter part of this period. Where 160 pounds per acre of each salt was applied, potassium chloride averaged 20 bushels per acre more potatoes than did the sulfate. Where the applications were doubled, giving an excessive supply, the sulfate plot was slightly more productive, and some toxic effects appeared on the chloride plot.

TABLE 63.—EFFECT OF SOURCE OF POTASH AND AMOUNT OF POTASH UPON YIELD OF POTATOES, IN BUSHELS PER ACRE
(*Brown*, 1923)

Source of potash	No potassium	Potassium, 3 per cent	Potassium, 5 per cent	Potassium, 7 per cent	Average
Chloride	...	235	240	245	240
Sulfate	...	230	234	231	232
Nebraska salts	...	230	233	225	229
Average	202	232	236	234	

Table 63 gives the average of 16 different experiments conducted in eastern states, 1,800 pounds per acre of a "complete fertilizer" being the standard application.

In these experiments, potassium chloride gave slightly higher yields. Other experiments, however, especially at the Massachusetts Station, have given best results with the sulfate. Probably, on most soils there is little difference in the value of the two salts for potatoes, while in some cases, one may be better than the other.

Potash and Quality.—Wheeler (1914) says:

> Muriate of potash is reported by many as giving slightly greater yields of potatoes than sulfate of potash, though the tubers are often claimed to be of inferior cooking quality. In field experiments in Rhode Island, potatoes of excellent cooking quality have been grown for 20 years with muriate as the sole source of K.

Wheeler thinks that the Cl in the soil resulting from applications of potassium chloride might become toxic, however, unless removed by heavy rains or neutralized by application of lime.

Brown (1923) concluded, from samples taken on eight different soil types, that the starch content of tubers treated with potash salts was not materially affected, compared to that of those grown without potash. Wallace (1921), at Bristol, England, found that high potash manuring in general, and of potassium chloride in particular, had no effect upon the flavor of potatoes or upon their cooking and keeping qualities. On the other hand, some investigators in Europe and the United States have reported different results. Voorhies (1892) claimed that manures, in general, resulted in a decrease of dry-matter content and that this loss fell especially upon the starch and that of the different forms of potash tested, sulphate reduced the dry-matter content least. Similar results have recently been reported from Rothamsted, England.

Source of Nitrogen.—The source of N may be important both from the standpoint of availability and of effect upon the reaction of the soil

TABLE 64.—YIELD OF POTATOES WITH N SUPPLIED FROM DIFFERENT MATERIALS, IN BUSHELS PER ACRE (*Brown*, 1923)

Source of nitrogen	Place and fertilizer formula used		
	Cape Charles, Virginia 6:8:6	Riverhead, New York 4:8:8	Presque Isle, Maine 4:8:8
Sodium nitrate	169	263	287
Ammonium sulfate	186	237	287
Ammonium nitrate	190	262	292
Ammonium chloride	184	247	300
Ammonium phosphate	192	248	296
Urea	206	259	300

solution. Table 64 gives the results of a 3-year test in three localities, applying 1,800 pounds per acre.

These data indicate that the source of N is not very important and that the best source may vary according to soil conditions. It is generally believed that rather slowly available nitrogenous materials and those acid in reaction are most satisfactory for potatoes. In New Jersey (Martin, 1923), where plots were treated with different nitrogenous materials continuously for 7 years, soil reaction and scab disease were much affected. Where all of the N was derived from nitrate of soda, the PH of the soil was 6.07, and 80 per cent of the tubers were scabby. With ammonium sulfate, the PH was 5.58, and only 30 per cent of the tubers were scabby. Organic materials, as fishmeal and tankage, gave intermediate results as to PH and scab control. Average yields for the 7-year period in the New Jersey experiment were about the same when all the N was supplied by nitrate, fish meal, or tankage. Distinctly larger yields were produced when the N was supplied from two or more different materials, however. On the alkaline soils of the western states, ammonium sulfate alone gives the best results.

Rotation.—The place of potatoes in rotation is usually after alfalfa in the West, after clover (in a grain—clover—potato rotation) in the East, and in rotation with other truck crops in the South. With potatoes grown under irrigation in Nebraska, Holden (1925) obtained the following results:

	Bushels per Acre
Continuous potatoes for 9 years	78
Rotation without alfalfa or manure	125
After alfalfa, in long rotation	290
Short rotations, receiving manure	217

Holden finds also that potatoes yield higher following sugar beets than after oats or corn. Reduction in yield under continuous potato culture is said to be due largely to diseases.

Irrigation

In the West, much attention has been given to the water relations of the potato plant. Experiments to determine the effect of frequency and amount of irrigation upon growth and yield have given results that vary with soil and climatic conditions. In southern Idaho, Welch (1914) found 21 acre-inches, in four applications, to be the optimum amount of water for yield. The yield was greater if the first irrigation was given when tubers were forming rather than earlier or later. Powers (1914), in western Oregon, concluded that potatoes should be irrigated whenever the moisture content of the top foot of soil dropped to 20 per cent of its

water-holding capacity. Harris (1917) reports that in Utah, applications of 1 acre-inch per week gave larger yields than did heavier applications at the same interval or at longer intervals. Harris tested 5-inch applications of water at four stages: (1) plants 4 inches high, (2) tubers beginning to form, (3) plants in full bloom, (4) crop nearly mature. With only one application for the whole season, the largest yield resulted from irrigation at the third stage; with two applications, the greatest increase was from irrigation at the third and fourth stages; and with three applications, at the second, third, and fourth stages. The full set of four 5-inch irrigations required 20, whereas the 1-inch-per-week treatment required only 12 acre-inches for the season and gave higher yields. Evidently, potatoes require light, frequent irrigations to keep the top foot of soil moist; moisture content of the lower levels is not so important.

Alternate high and low soil-moisture content causes cracking and other abnormal tuber developments. After tuber development has been arrested by the dryness of the soil, an irrigation causes rapid expansion in the region of the eyes, and knobby second growths form.

Harvesting

Most of the potatoes grown in this country commercially are harvested with elevator digging machines. The elevator apron of the digger may be operated by wheel traction or by a small auxillary engine. Because of the danger of bruising, immature potatoes are often plowed out and gathered by hand.

The time to harvest a field of potatoes is often an important consideration. The tubers continue to enlarge at a somewhat constant rate, until the tops are dead. Hence, the largest yield and highest proportion of U. S. Grade No. 1 tubers is produced by allowing plants to grow to full maturity. On the other hand, prices may be high early in the season and are likely to decline later, thus more than offsetting the gain in yield. In general, potato production in the United States falls into two classes: (1) Main-crop potatoes are grown in the North and West; they grow to full maturity or until killed by frost; the tubers are mature when harvested and are mostly placed in storage for winter markets. (2) Early potatoes are grown in the southern states, from Maryland to southern California; they are dug while the tops are green and the tubers are immature, being shipped to market at once. The intermediate regions, from Long Island and New Jersey, westward, grow both the early and the main crop.

With full maturity, an important change is the increase in the thickness and toughness of the periderm. In partly grown or unripe tubers, this is thin and rubs off easily, exposing the cortex. Oxidation takes place rapidly, and the exposed areas become blackened. As the tubers mature, the periderm thickens by tangential division of cells and suberization of the walls. This process forms a skin resistant to injury.

When potato plants are killed by frost or late blight, 10 days to 2 weeks are required for the thickening of the periderm. This can be brought about earlier by killing the plants with a copper-sulphate or sodium-arsenite spray. To do this, however, reduces yields.

Marketing

Producing Regions.—Commercial production is centralized in certain districts each of which has its characteristic style of pack, varieties, and shipping seasons. Aroostook County, Maine; Long Island; western New York, southern New Jersey; the eastern shore of Maryland and Virginia; eastern North Carolina; Charleston, South Carolina; and Hastings, Florida, are the most important districts in the Atlantic states. In the Middle West, the important sections are the Red River Valley of Minnesota; the sandlands of northern Wisconsin and Michigan; the Kaw Valley of Kansas; Greeley, Colorado; Fort Smith, Arkansas; New Orleans, Louisana, and the lower Rio Grande Valley of Texas. On the Pacific coast, the delta district of California, the Yakima Valley of Washington, and the Snake River Valley in southern Idaho are most important. Table 65 gives the carlot shipments and usual shipping seasons for the important potato states.

Table 65.—Leading States in Potato Shipments, with Main Shipping Season and Carlot Shipments for Period, 1922–1926

State	Main shipping season	1922	1923	1924	1925	1926
Alabama	May, June	1,923	1,388	2,917	1,049	2,221
California	May to February	8,215	6,765	6,247	6,169	7,257
Colorado	August to May	16,134	15,141	13,946	14,146	15,374
Florida	March to May	5,046	3,497	4,381	5,137	4,824
Idaho	August to May	13,834	17,595	13,685	14,328	19,495
Kansas	July, August	2,434	3,563	4,800	2,736	4,038
Maine	September to June	32,783	31,016	34,850	44,087	40,124
Maryland	July, August	3,397	2,827	2,912	1,653	1,990
Michigan	September to May	16,204	19,380	20,275	18,444	13,887
Minnesota	July to May	27,915	32,275	30,894	28,467	22,487
Nebraska	August to May	4,835	4,774	3,904	4,218	3,825
New Jersey	July to November	18,208	6,501	8,671	3,454	4,712
New York	August to May	17,658	17,695	18,904	18,736	12,468
North Carolina	May to July	4,202	3,475	6,566	4,052	6,695
North Dakota	September to April	7,019	10,342	6,413	6,246	4,685
Pennsylvania	September to March	5,138	3,647	4,308	6,373	2,738
South Carolina	May, June	4,352	4,211	5,266	3,675	5,211
Virginia	June to August	19,169	15,883	23,776	15,809	16,286
Washington	September to June	4,934	5,907	7,061	7,479	10,304
Wisconsin	September to April	15,665	19,536	16,269	19,196	14,464
Total for United States		229,698	241,523	252,095	241,554	229,698

The states leading in carlot shipments are not always those with large acreage. The southern states ship a much larger per cent of their crop than the northern ones do. Thus, Pennsylvania is one of the leading potato states in acreage, but its carlot shipments are small, because most of the crop is consumed locally.

Shipping Seasons.—Beginning in April, with Hastings, Florida, and southern Texas, the various districts follow each other and have rather short shipping seasons. By the end of July, the potato harvest has advanced northward to the intermediate states, and by the middle of September, to the main-crop states along the northern border. October is the month of heaviest shipments from the main-crop states, but a good volume moves throughout the winter and into the late spring. The price of early potatoes from the South is materially affected by the size of the main crop in the North the preceding year.

Packages.—The standard U. S. barrel, which holds slightly over 3 bushels, is much used in Maine and in the south Atlantic states. It may have a solid head or a burlap cover. Barrels are expensive, but when used, the minimum amount of bruising occurs. Sacks are extensively used for main-crop potatoes; 180-, 165-, and 120-pound bags are three standard sizes, the last being used especially in the Middle West and Pacific coast states. Lug boxes, which hold 30 pounds, are used for extra-early potatoes on the Pacific coast. A potato package should be clean, attractive, and prevent bruising. Potatoes are often handled in bulk in the northern states, particularly in harvesting and warehousing and sometimes in shipment.

Grading.—Most potatoes, except those going on the market as extra early, are graded. The U. S. grades for potatoes are modified somewhat from time to time, but the essential points are as follows: In U. S. Grade No. 1, the minimum diameter is $1\frac{3}{4}$ for long and $1\frac{7}{8}$ inches for round varieties. This grade must be free from disease, insect or mechanical injury, and such defects as growth cracks, hollow heart, and second growth. A tolerance of 5 per cent by weight is allowed on size and an additional 6 per cent, on combined defects. U. S. Grade No. 2 is similar, but the minimum diameter is $1\frac{1}{2}$ inches. Grading for size is accurately done by various grading machines. This is supplemented by hand picking to remove defective tubers.

Storage

About one-half of the potato crop is stored before passing it into the channels of trade. The objects in the control of potato storage conditions are (1) to prolong the life of the tuber, (2) prevent undue shrinkage, and (3) prevent impairment of culinary or seed value. The tubers must be kept dormant, without freezing or decay. Shrinkage previous to

sprouting is due to loss of water through evaporation and to destruction of solids by respiration.

Appleman (1922) says:

> The storage life of a potato may be divided into distinct periods, each characterized by a predominance of certain physiological and biochemical processes. Storage conditions that are most favorable or allowable for one of these periods, may not be best in others.

These periods are as follows: (1) Early part of rest period. Continuation of synthetic, or ripening, processes predominates, sugar changes to starch, the skins become corked, and the shrinkage from water loss is high; (2) The latter part of rest period. Building up and decomposition processes nearly balance in this stage; (3) Dormant period, between the time when the potato is able to sprout and the time when sprouting actually begins. Hydrolysis, or breaking-down, predominates, probably due to weakening of the synthetic processes; this tendency increases with the age of the tuber. Softening of the tuber in late storage is due probably to breaking down of certain cell-wall materials; (4) Sprouting period, characterized by high destructive metabolism, resulting in loss of solids. There may be rapid loss of water by evaporation from the sprouts.

Temperature Effects.—The lower the temperature, especially during late storage, the longer the life of the tuber; but long exposure to temperatures near freezing impairs culinary quality. Many years ago, Müller-Thurgau showed that potatoes stored near the freezing point became sweet, because of the conversion of starch to sugar. He found also that some of the sugar was reconverted to starch after removal to higher temperatures. Appleman (1914) shows that the starch-sugar change is controlled by storage temperature and is not necessarily connected with the age of the tuber or with the ending of the rest period. Low temperature during the natural rest period is important in that it limits respiration and transpiration losses. Potato tubers have a high respiration rate, which varies with the temperature from a maximum at 43 to a minimum at 3 to 5°C. Respiration actually increases as the temperature is lowered from 3 to 5°C., to 0°C.; this has been proved by Bennett and Bartholomew (1924) and by Hopkins (1924). The former writers found that blackheart, an O_2-deficiency trouble, occurred in 1 day in tubers held at 25 to 30°C. in an O_2-free atmosphere. The length of time required to produce blackheart increased, as the temperature was lowered, to 42 days at 5°C.; but below this point, the time to induce blackheart decreased to 7 days at 0°C. They show that these results are due to minimum respiration at about 5°C., the respiration rate increasing as the temperature is either raised or lowered from this point. Hopkins found the minimum respiration at about 3°C. For minimum loss by respiration, 3 to 5°C. is the most satisfactory temperature for potato

storage. The sweetening caused by sugar accumulation is only moderate at this temperature, and sprouting is inhibited.

When potatoes from cold storage are transferred to a higher temperature, they respire at an abnormally high rate for a few days, but the rate gradually falls back to the normal for the existing temperature. This outburst of respiration is a serious factor in marketing cold-stored potatoes, for it causes heating and shrinkage. It is an additional reason for avoiding temperatures near 0°C. While it is often claimed that cold storage shortens the rest period or results in more prompt sprouting than does storage at high temperatures, Rosa (1926) finds that this is not true. Freshly dug tubers stored for 1 month at 30°C. and than planted, sprouted sooner than those stored at 12 or 22°C., while tubers stored at 4°C. were somewhat slower in sprouting than were the latter.

Humidity.—High relative humidity of storage air prevents shrinkage through water loss from the tubers. Low humidity hastens the formation and corking of the periderm, which serves as a check to subsequent water loss. Too much moisture in the air favors the growth of decay organisms and favors sprouting during late storage (if the temperature is above 7 or 8°C.). Marble (1923) showed the importance of humidity control through ventilation and proper storage-house construction. He finds that sweating, due to the excretion of water from the tubers, occurs when potatoes are stored in bins and that decay follows. Storage in sacks or crates is preferable. Keeping the humidity rather low, by forced ventilation, was found by Marble to have an effect comparable to low temperatures in keeping potatoes in a sound, unsprouted condition. Four air changes per hour kept tubers dormant a month longer than did one change in 24 hours. Relative humidities below 65 per cent should be avoided, but at from 65 to 95 per cent relative humidity, the shrinkage is not excessive, after the skins have become well corked over.

Varieties

Salaman (1926) defines a potato variety as "a group of identical plants sharing the distinctive characters of an original individual from which they are derived by vegetative reproduction." No matter how long the variety is propagated by vegetative buds, or eyes, all the plants represent merely the divisions of a single individual. Varieties of this kind are called "clones."

A few years ago, hundreds of varietal names were current in the United States. Many of these were seedsmen's or local synonyms. Many varieties have disappeared, being superceded by better ones, or destroyed by virus diseases. The prevalence of virus diseases in most parts of the United States makes it difficult to preserve local varieties. Further-

more, the commercial development of the potato industry has made it imperative to grow only a few important market types. Stuart (1915) classified American potatoes into 12 varietal groups, using tuber, sprout, and flower characteristics as the basis of his classification. His classification follows, with some notes as to representative varieties, season of maturity, and commercial importance:

Group 1. Cobbler.—Tubers roundish; skin creamy white; sprouts tinged with reddish violet; flowers light rose-purple. Irish Cobbler and Early Eureka are the principal varieties. Cobbler is almost the only variety used in the south Atlantic states; it is also important for early crop in the Middle West and North.

Group 2. Triumph.—Tubers roundish; mottled or solid red; sprouts more or less deeply suffused with reddish violet; flowers light rose-purple. Bliss Triumph, Stray Beauty, and Quick Lunch are nearly identical representatives. Used chiefly in the Gulf states and for the extra-early crop in the Middle West.

Group 3. Early Michigan.—Tubers oblong or elongate flattened; skin creamy white; sprouts light rose; flowers white. Season medium early. American Giant, Wisconsin Pride, and California White Rose are identical varieties probably belonging to this group. In the East, the tubers are usually coarse and deep eyed, but in California, the tubers are smooth, symmetrical, and of excellent quality.

Group 4. Rose.—A large and variable group. Tubers roundish oblong, elongate flattened, or spindle shaped; skin pink, flesh colored, or white; sprouts cream to rose lilac in color; flowers white (lilac in Section 3—see below). Varieties which are early, medium, late, and very late belong to this group.

Section 1. Tubers flat oblong, Early Rose, Vermont, Late Rose

Section 2. Tubers broad roundish, King, Spaulding Rose No. 4

Section 3. Flowers lilac purple, New Scotch Rose and Seneca Beauty.

Group 5. Early Ohio.—Tubers oblong or ovoid; skin light pink; sprouts more or less deeply suffused with carmine lilac; flowers white. Season medium early. Early Ohio and Early Six Weeks are representative varieties. Important in the Middle West.

Group 6. Hebron.—Tubers flattened, elongated, or spindle shaped; skin creamy white or splashed with light pink; sprouts light lilac or free of pigment; flowers white. Medium early in maturing. Beauty of Hebron and White Beauty of Hebron are representatives. No longer grown extensively.

Group 7. Burbank.—Tubers long, flattened, or spindle shaped; sprouts faintly tinged with magenta; flowers white. Late maturing. Most important on the Pacific coast and in Idaho.

Section 1. Skin white to dull white, smooth to glistening. Burbank, Pride of Multnomah, Low-Top Burbank.

Section 2. Skin russet, heavily netted or reticulated. Russet Burbank, Netted Gem.

Group 8. Green Mountain.—Tubers moderately oblong, broad, and flattened; skin dull-creamy or light-russet color, often having russet-brown patches toward the apical end; sprouts white (becoming green in light); flowers white. Medium-late maturing. One of the most important commercial types, especially in the northeastern states.

Section 1. Sprouts white. Carmen No. 1, Gold Coin, Green Mountain.

Section 2. Sprouts white at base, leaf scales tinged with lilac. Charles Downing, Idaho Rural, and Earliest of All.

Group 9. Rural.—Tubers round, flattened to short oblong; sprouts violet purple; flowers purple, with five points of corolla white or nearly so. The plants have an erect, straggly, little-branched, brownish-purple stem, which distinguishes this group. Important main-crop variety throughout the North.

Section 1. White skin. Carmen No. 3, Rural New Yorker, Sir Walter Raleigh.

Section 2. Russet skin. Rural Russet, Late Petosky, Dibbles Russet.

Group 10. Pearl.—Tubers round flattened to heart shaped; skin dull white or dull russet (or blue in Section 2). Sprouts faintly tinged with lilac; flowers white. Season late. Important in Colorado. Varieties of Section 1 are Pearl, Peerless, People's Russet, and of Section 2, Blue Victor.

Group 11. Peachblow.—Tubers round flattened or round oblong; skin creamy white splashed with red or pink; eyes bright carmine; sprouts suffused with reddish violet; flowers purple. Includes both early and late varieties but is chiefly important for fall crop in the middle Atlantic states and in Colorado. Varieties are Early Peachblow, Jersey Peachblow, McCormick, Round Pinkeye.

Group 12. Up-to-Date.—Tubers short oblong, flattened; skin yellowish white; sprouts purple; flowers purple. Plants are unusually large and vigorous. Apparently a recent introduction from England. Important in the Pacific states, where it is grown under the misnomer "British Queen." Cultivated locally in several central states, especially for the fall crop.

Breeding

Efforts on potato improvement have followed two lines: (1) selection within the clone and (2) sexual propagation, followed by selection among the progeny for desirable individuals, which are then propagated asexually. Nearly all varieties have originated by the second method.

Improvement by the selection of tubers from heavy-yielding or otherwise desirable plants has been much recommended in potato literature of the last 50 years, but little has come of the suggestion. Such selection assumes that heritable differences exist between the different individual plants in a vegetatively propagated variety, or clone. These differences might arise as somatic mutations. Abrupt and permanent changes in such characteristics as color of tuber are sometimes observed, although they are not frequent. Similar variations having to do with yield may also occur, but it is extremely difficult to observe or to isolate them. To isolate lines of superior yield, the progeny of thousands of plants might have to be studied. A further difficulty is that soil variation tends to obscure differences in yielding power, when one is dealing with small, single plots, such as would exist in the first year of a selection experiment. It is necessary to propagate the selections 2 years, therefore, in order to have sufficient material to plant replicated plots and to secure reliable yield data. A further difficulty is that some or all of the selections may become infected with virus diseases. The apparently favorable results which sometimes follow the first year of single plant selection, have been due, no doubt, to the fact that the parental stock was infected to some extent with virus diseases. Myers (1924) is about the only American worker who has reported the isolation of high-yielding strains by selection; disease, apparently, has not influenced his results. MacKelvie (1921) has reported the occurrence of mutations in the Arran Victory variety, which differed not only in tuber color but in form of tuber and plant type. Myers has observed also variations within tuber lines, involving shape and color of tuber and plant. Darst (1924) collected and examined all available cases of mutations in the potato. He lists 21 distinct variations in the variety Eigenheimer, and many in other varieties.

Krantz (1923), on the other hand, showed that two strains of Early Ohio, which had been selected for vigor and type for 20 and 21 years, did not differ significantly in yield from other, unselected, strains. Krantz further showed that variations in tuber type are connected with environmental conditions and are not transmitted. Stuart (1915) obtained great differences between selected lines of potatoes. He concluded that causes other than inherent non-productiveness must have operated to lower the yield in certain cases. He pointed out that selection methods are chiefly useful to eliminate unproductive and diseased individuals. To do this is, indeed, at present the chief use of selection in potatoes. The methods used are as follows: In *hill selection*, the individual plant is the basis. In *tuber-unit* work, a number of tubers are tested individually without reference to their parents. In *tuber indexing*, one eye is removed from each tuber and grown to a stage that reveals whether the tuber from which it came is disease free or not. Healthy material, isolated by any of these methods, is then planted in a seed plot

for multiplication. Usually, a few diseased plants appear, even in plots from indexed tubers, and these are removed by occasional roguing. Under conditions where virus diseases spread rapidly or where they are masked by climatic conditions, even the most careful selection and roguing may fail to keep up the productivity of a variety over a period of years.

From 1850 to 1890, many new varieties were developed in the United States from cross- or open-pollinated seed. But little has been learned concerning the genetics of the potato, because many varieties are self-sterile, and all are heterozygous. Seeds from either self- or cross-fertilization give rise to a variable progeny. Recently, Krantz (1924) has obtained the first and second inbred generations in several varieties, and this line of work will furnish reliable material for genetic studies. He finds that F_1-generation hybrids of commercial varieties are more vigorous than seedlings obtained by selfing the parental varieties. Since the vigor of such hybrids may be maintained through vegetative propagation, this is a way to obtain high-yielding varieties, though it is difficult to find parental ones which give the desired combination of characters in the F_1 generation. It was also found that vigor, yield, and period of maturity in seedlings were sufficiently representative of their subsequent behavior, to permit selection safely the first year. Although a reduction of vigor occurs in the first and second inbred generations, the seedlings become more homozygous. Selection within self-fertilized lines, with subsequent crossing to regain lost vigor, will be the most practical method for potato improvement.

The investigations of Salaman and Lesley (1922) indicate that male sterility (of varieties producing only abortive pollen) is a dominant genetic factor. Sterile plants may, however, appear in the progeny of crosses between some fertile varieties. Sterility is not completely dominant, for a little viable pollen and some seeds may be produced by F_1 plants from sterile $\times$ fertile crosses. Salaman and Lesley (1923) showed that immunity to wart disease is dependent upon dominant factors, at least two genes being involved. Upon selfing immune varieties, some were found to be homozygous, giving all immune progeny; others gave immune and susceptible plants in 15:1, 3:1, and 9:7 ratios. The breeding of varieties resistant to other diseases is an attractive field, but the limited amount of work which has been done indicates more complicated relationships than those existing in wart disease. Fortunately, virus diseases are not transmitted through sexually formed seed, and disease-free varieties are obtained by resorting to sexual propagation.

It has been shown that shallow eyes are dominant to deep ones, and that particolored and solid-colored skin are dominant over white, though Stuart (1915) found that white is not always recessive. Krantz (1922) finds that the three primary tuber shapes (round, oblong, and long) are

essentially dependent upon the presence or absence of a single factor for length. Crosses between late varieties can give rise to early types—season of maturity is controlled by definite segregating factors. Krantz found much variability in regard to this characteristic in F_1 and in F_2 generations from crosses of commercial varieties.

The varying degrees of pollen-sterility in many varieties make it difficult to determine accurately the mode of inheritance of certain characters, and investigators working with different varieties sometimes obtain different results. Furthermore, at the Maine Experiment Station (1925), it was found that, while some varieties were orderly in their chromosome behavior, others show lagging chromosomes at the reduction division. This fact indicates the hybrid origin of some varieties and leads us to expect irregularity in their hereditary behavior. In cultivated varieties of potato, the haploid-chromosome number is 24, while in the wild species, the number varies from 12 to 36 but always in multiples of 12.

I. Bacterial and Fungus Diseases

Common Scab (*Actinomyces scabies*).—The causal organism is one of the higher bacteria and is widely distributed. It may even occur in virgin soils. Only the tubers are attacked, and the chief loss is due to non-salability of scabby potatoes. The symptoms are pits, or raised scabby areas of corky tissue, on the tuber. Control consists of disinfection of seed tubers before planting, though if the soil is already infected, this may only slightly reduce the amount of scab. The scab organism is sensitive to the reaction of the soil, being most injurious in neutral and alkaline soils. In soils with a Ph of 5.2 or less, scab does not develop in appreciable amounts. As potatoes grow well in acid soils, that fact is taken advantage of in scab control. Soils in the East, by application of 300 to 600 pounds of S to the acre, can generally be made sufficiently acid to control scab. In the soil, the S is oxidized to sulfuric acid by sulfofying bacteria; unless such organisms are present, S will have little effect. Martin (1923) showed that inoculated S gave the greatest reduction in the amount of scab in New Jersey. Since tubers pass through a stage of scab susceptibility early in their development, it is especially necessary to have the acid-soil reaction at that stage. Best results were obtained by broadcasting the S before planting. The use of sulfate of ammonia, which gives an acid reaction, was also found to reduce scab considerably; lime and nitrate of soda, which are alkaline materials, increased it. Where the soil is made acid to control scab on potatoes, the condition has to be corrected by application of lime, before acid-sensitive plants, such as onions or spinach, can be grown.

Crop rotation reduces the amount of scab. At the Nebraska Experiment Station, in plots planted to potatoes continuously, the tubers

became so scabby that they were not marketable; under a 4-year rotation, the scab was reduced; and with a 6-year rotation, the potatoes were generally scab free. Sanford (1923) found that potatoes grown in rather dry soils were severely scabbed but that in moist soil, the tubers were nearly all clean. Under irrigated conditions, this factor might well be controlled during the susceptible period just after tuberization.

Black Leg (*Bacillus atrosepticus*).—Black leg often causes severe losses to potatoes in the North and is sometimes the cause of poor stands from northern seed planted in the South. Low, poorly drained soils and wet weather favor its development. The lower part of the stem is the region generally attacked, although the bacilli invade also the tuber and cause a characteristic decay. Stems become blackened from seed piece, upward. The soft, black decay, involving the whole stem, is distinguishable from the brown, patchy decay of Rhizoctonia involving the cortex. The tops become stunted, turn yellow, and fall over. Plants may become affected late in the season, the organism entering the tubers through the stolon and causing a firm, brown or black decay. The bacilli are said not to live over winter in the soil or in diseased plant tissues left in the field, hence, seed tubers are the important mode of dissemination. The bacilli are spread on the cutting knife to healthy sets. Use of healthy seed is the most important control measure. Discarding all seed tubers which show external evidence of infection and disinfecting in corrosive sublimate those that appear to be sound are helpful measures. To use seed tubers produced in a field where the disease was not present the previous year is best.

Rhizoctonia (*Rhizoctonia solani*).—This disease occurs in most parts of the country and is a cause of extensive loss, especially early in the season when cool weather prevails. A resting stage of the fungus gives rise to the sclerotia—superficial, raised specks on the tuber. When numerous, these sclerotia detract from the appearance of the tuber, but they occasion no particular damage. Most of the injury is due to lesions on the underground part of the stem. Longitudinal areas of a firm, brownish, cortical decay are most frequently seen. If conditions favor, the stem may be completely girdled. Then the tops become yellowish, aerial tubers may appear in the axils of the leaves aboveground, and development of underground tubers is inhibited. Tuber production may be curtailed also by destruction of the stolons before tuberization. Another type of injury is through the death of sprouts before they reach the surface of the soil; other sprouts may arise from the seed piece or from the base of the first sprout, and these may also be killed by the fungus. If sprouts finally reach the surface, they produce only weak plants.

The fungus overwinters in the soil and on tubers, either as active mycelia or as sclerotia. It can probably persist indefinitely in cultivated

soils and is native to some virgin soils. This fungus, moreover, attacks a very wide range of host plants, both wild and cultivated. The virulence of the disease seems to become greater, however, when potatoes, beans, or other favored hosts are grown continuously.

The occurence of Rhizoctonia in destructive form depends largely upon some environmental factors and their effect upon host and parasite. Richards (1921) has shown that soil temperatures have a marked effect. While infection may occur at any temperature between 9 and 27°C., the greatest pathogenicity of the fungus occurs below 21°C. The effect of higher temperatures upon the fungus explains why, in the South, losses

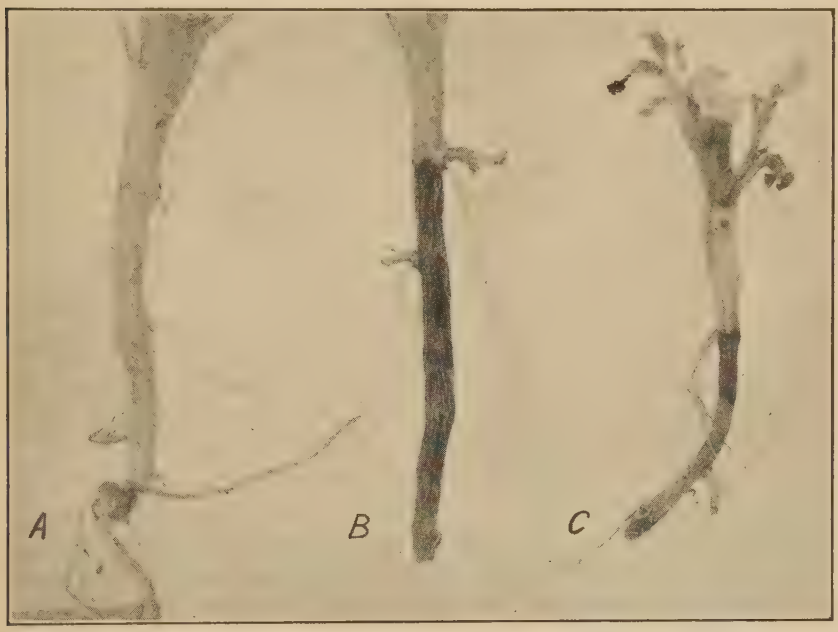

FIG. 69.—B and C show lesions of Rhizoctonia on the underground part of potato stems. A is a healthy plant.

from this disease are uncommon, except where diseased seed are planted without disinfection. The lower the soil temperature, the slower the growth rate of the sprouts, and the greater the period of exposure to infection. The fungus may attack the plant in all stages of development but is most destructive upon young sprouts. Late planting may lessen the losses from Rhizoctonia but is often undesirable from other standpoints. The most important control measure is disinfection of seed. Immersion for 1½ hours in mercuric chloride, 1:1,000, has been shown to eliminate 90 per cent of tuber-borne infection. Even where soil infection exists, losses are reduced by seed treatment. The hot-formaldehyde is as effective as the mercuric-chloride method of treatment and is

much cheaper and more rapid for large quantities of seed. The seeds are immersed in a solution of 1 pound of formalin to 15 gallons of water, at a temperature of 48 to 52°C., for 3 to 5 minutes, then covered with a canvas to retain the fumes.

Early Blight (*Alternaria solani*).—This fungus disease is called "early blight" to distinguish it from late blight (Phytophthora), both being primarily foliage diseases. Early blight is widely distributed and causes much damage in unusually moist and warm seasons. The optimum temperature for spore germination and growth of the fungus is 26 to 27°C., according to Rands (1917). This same fungus attacks tomato, eggplant, and other *Solanaceae*. The lesions on the foliage consist of dark-brown, circular spots, which appear on the lower leaves first and usually originate in a wound caused by insects. These spots are distinguished from those of other diseases by their distinct, concentric rings. Spots coalesce, leaves fall, and the yield of tubers is decreased because of this premature defoliation.

The fungus overwinters in the soil on decaying vegetation or on wild hosts, whence the spores are spread by the wind to potato plants. Control is effected by spraying with Bordeaux mixture, eradication of Solanaceous weeds, and crop rotation.

Late Blight (*Phytophthora infestens*).—Late blight is generally limited to the North; and even there, it occurs in epidemic form only occasionally. The disease occurs also at high elevations in the South, but in Florida on the winter crop, and in cool regions along the Pacific coast. Melhus (1915) found that the optimum temperature for indirect spore germination (production of zoospores) was about 12 to 13°C.; direct germination (by germ tubes) took place at higher temperature, the optimum being about 24°C. The latter method provides for much slower dissemination of the fungus and indicates why, for one reason, the disease is not serious in warm regions.

All aboveground portions of the plant, as well as the tubers, are attacked. Lesions generally appear first on the lower leaves as irregular, black patches near the margin. The adjoining healthy tissue turns yellow; and on the underside of the leaf, wefts of white, sporulating conidiophores appear. Tuber infection results through contact at harvest time with spores dropped upon the soil from leaf and stem lesions. As the spores are short lived and are killed by frost, tuber infection can be avoided if harvest is deferred for 2 or 3 weeks after the plants are completely dead. Infection of the tuber results in small, sunken, purple-black spots on the surface; and in the early stages, there occurs a reddish decay of the flesh below the surface. This may be followed by soft rot, resulting from invasion by saphrophytic organisms. Hence, tubers from plants affected by late blight are subject to extensive loss by decay in storage, unless held at 4°C. or less.

The fungus overwinters only in the tubers, either as mycelium or as resting oospores. When infected tubers are planted, the mycelium grows from the seed piece through the stalk to the surface, where it sporulates. Spores are spread by wind, rain, and insects to other plants. The fungus does not overwinter in the soil, so the use of healthy seed should prevent the disease. Slightly diseased tubers are not readily detected, however, and disinfection is not effective. Moreover, the spores can be spread great distances by air currents. The standard control measure is to spray the plants four to six times during the growing season with Bordeaux mixture. Spraying is chiefly a preventative; hence, it must be started before the advent of the disease in epidemic form. Experiments in New York, Vermont, Wisconsin, and Iowa show that the Bordeaux spray controls the disease in epidemic years, with resultant large increases in yield. Furthermore, some increase in yields results from spraying in non-blight seasons, because spraying controls minor diseases.

There is considerable resistance to late blight in certain varieties, and the ultimate control will no doubt be a resistant variety. After extended trials of American and European varieties, however, Stuart (1914) concluded that no existing variety combined resistance with high yield or with tuber characteristics desirable from the American point of view.

Fusarium Wilt (*Fusarium oxysporium*).—Several other species of Fusarium (*F. radicicola*, *F. eumartii*, and others) are known to cause wilts of potato, but the general nature of attack and control are about the same. Fusarium wilts cause extensive losses in widely separated parts of the country. The causal organism is a saphrophytic soil fungus, which becomes parasitic upon potatoes under certain conditions. Infection takes place through the roots: the fungus passes into the stem and thence, through the stolons into the tubers. Aboveground portions of the plant turn yellow and die, presumably because of the excretion by the fungus of a toxin. Goss (1924) showed that blocking of the xylem vessels did not occur in the wilt caused by *F. eumartii*. Vascular discoloration in the stems is a valuable diagnostic symptom; this may also appear in infected tubers, especially near the stem end. Since other agencies may likewise effect similar discoloration, this is of no value in selecting disease-free tubers. Furthermore, McKay (1921) shows that tubers may be infected with wilt yet show no discoloration. Cultures from over 2,000 tubers revealed the fact that 55 per cent of those with stem-end browning were free of disease fungi, while 22 per cent of the tubers which were yellowed, and 5 per cent of those not discolored contained wilt-producing organisms. Infection of the plant and the development of the disease is much influenced by environmental factors. Goss (1923) finds that infection may result in no visible evidence of disease, if growth conditions for the plant are favorable. He finds also that the

disease decreases with soil temperatures below 18°C. and increases rapidly with higher temperatures. High soil moisture favors the rotting of infected stems and roots. Infected tubers do not produce infected plants, unless conditions are very favorable for the disease. Plants from such tubers are often weak, however. Wilt fungi are indigenous to some soils. They can survive, also, indefinitely when once introduced though long rotations greatly reduce infection. The disease is transmitted through infected seed tubers, and, since the parasite is within the tuber, disinfection is not effective. Disease-free seed can be obtained only from fields where the disease did not exist or from which wilt-infected plants have been removed early in the growing season. McKay shows that tubers borne on healthy plants adjoining wilted ones are likely to be diseased. Hence, in roguing, the plants next to those affected with wilt should be removed.

Verticillium Wilt (*V. albo-atrum*).—Verticillium causes a wilt disease similar to that caused by Fusarium. The former requires rather low temperatures; hence, occurs only in the cooler regions, seldom where Fusarium wilts are virulent. Vascular discoloration is not so marked, in stems and tubers, as it is in Fusarium wilts, and the decay of stems and tubers does not occur. Infection, life history, and control for the two diseases are similar. McKay (1926) found that in Oregon, Verticillium lives over winter in diseased-plant remains and that a 2-year rotation was not effective in avoiding soil infection. The disease was almost eliminated, however in 3- and 4-year rotations with cereals and legumes.

Tuber Rots.—Potato tubers are subject to various types of decay while in transit or storage. Rots caused by late blight and black leg organisms have already been mentioned.

Leak is a soft, watery decay, occurring shortly after harvest in tubers dug during hot weather. Invasion of the tubers through wounds, by Pythium and perhaps other fungi, is the cause. Allowing the tubers to grow to full maturity, avoiding wounds made by breaking of knobs, and digging by machine instead of with hoe forks has lessened the trouble.

Jelly end rot is a decay of the stem end or of second-growth knobs. It is caused by Rhizoctonia, Fusarium, and perhaps other organisms.

Powdery dry rot is a storage disease arising through wounds. The affected portion of the tuber becomes brown, dry, and shrunken. Powdery dry rot is caused by *Fusarium trichothecioides*. Other storage rots are also caused by Fusarium. Prevention of bruising in harvesting and provision of good storage conditions lessen all of these diseases.

Frost injury may occur in the field, in storage, or during shipment in cold weather. Slight injury may occur when the tubers are exposed to −2°C. The vascular ring is darkened and necrotic patches or streaks

appear in the pith. Lower temperatures result in the freezing solid of portions or of all of the tuber, and this is followed by soft decay.

II. Virus Diseases

This term is applied to a group of plant maladies, for which the causal organisms are unknown and which are not due primarily to unfavorable environmental conditions. These maladies, indefinite though they often seem to be, are none the less real. They are characterized by being infectious and are spread from plant to plant in juice transfers made by insects or other agencies. They are hereditary through the tuber but not through the seed. They have been referred to as "degeneration diseases," since they are the cause of what was formerly considered to be degeneration, or "running out." Virus diseases have been recognized as such only recently but have probably existed ever since potato cultivation began. They have definite symptoms, interfere with normal plant development, and cause reduction of yield in varying degrees. As a group, they are the most baffling and the most difficult to control. Some 20 or more are now recognized, though only a few of the more important ones may be discussed here. For all of them, the only means of prevention is the use of non-infected seed. This requires that the seed tubers be produced where these diseases do not spread rapidly, and that careful roguing of the seed fields be practiced. Sprouting the seed for the seed plot, before planting, and discarding tubers with weak sprouts lessen the amount of roguing necessary.

Leaf Roll.—This was the first virus disease to be recognized as such, by Quanjer in Holland, in 1907. The first symptom is a rolling of the leaves upward, parallel to the midrib. They stand erect, are stiff, and are somewhat tinted with pink or yellow. The plants become stunted, and the yield is much reduced. All parts of the plant become gorged with starch, because translocation of carbohydrate is interfered with by necrosis of the phloem strands. Phloem necrosis is not always evident in the stem or tubers of affected plants, however. Tubers from leaf-roll plants often, but not always, produce spindling sprouts, though there are other causes of this condition. Leaf-roll symptoms are expressed definitely in most regions, and the rate of spread is not so rapid as in other virus diseases. Hence, roguing is easy, and leaf roll is on the decrease in this country.

Mosaic.—Mild, crinkle and rugose mosaics are recognized by Schultz and Folsom (1923) as distinct diseases, which maintain a more or less constant plane of severity and do not become progressively more severe. Double infection, of mosaics and other diseases, is more destructive. These diseases, in general, cause wrinkling and ruffling of the leaf and dwarfing of the whole plant. The most definite symptom is the mottling of the leaves, with patches of tissue lacking in chlorophyll. The appear-

ance of mottling, however, and, to a lesser extent, of other symptoms, depends upon environmental conditions. Goss and Peltier (1925) show that light, soil moisture, and soil temperature have little effect upon foliage symptoms of virus diseases in general, though mosaics may best be seen in semi-shade. Air temperature was found by these workers to be the chief factor in masking, or expression; all symptoms of the mosaic disease were more distinct at 14°C. than at higher temperatures and disappeared in plants grown at 25°C. or higher. Mottling was slight at 22°C. This fact renders efficient roguing impossible in regions having a warm growing season. Tubers borne on plants in which the disease is masked nevertheless contain the virus and produce diseased progeny. Experiments in Maine, under favorable growing conditions, showed the following reduction in yield by virus diseases: Mild mosaic, 8 to 25 per cent; rugose mosaic, 50 to 60 per cent; and spindle tuber, 20 to 25 per cent. Mosaic diseases occur in other species than potato and in many cases are intertransferable. Interspecific infection is not proof of the identity of the typical mosaics of different species, however. The work of Fernow (1925) indicates that potato mosaic is transferable to and from many other *Solanaceae*, including tomato, tobacco, and some common weeds.

Curly Dwarf.—This represents almost the extreme in degeneration diseases. The plants are very much dwarfed and may die before the end of the season. Mosaic symptoms are intensified, and they do not disappear with changing environment. It is thought that curly dwarf is a combination of mosaic and spindle tuber.

Spindle Tuber.—This condition, known for many years in the Middle West as "running out," was not recognized as a virus disease until recently. The investigations of Werner (1923 and 1926), in Nebraska, have been most important. Spindle tuber is common in both Atlantic and Pacific states. It owes its name to its effect on tuber shape. They become abnormally long and pointed at the ends, or spindle shaped. Such tubers give rise to plants which are small, erect, and less productive than are healthy plants. The leaves of spindle-tuber plants are sharp pointed, narrow, attached to the stem at an acute angle, and slightly rolled at the margins. Symptoms of infection in the tuber are not always expressed, especially in current-season infection. Werner finds also that tuber symptoms are less distinctly developed at low soil temperatures and on light, sandy soils. The leaf symptoms, contrary to those of mosaic, increase in distinctness and severity with increased temperature, being much more evident at 25 than at 15°C. Roguing of plants for both mosaic and spindle tuber cannot be done effectively under the same temperature conditions. Spindle tuber is said to become progressively more virulent after infection occurs, so that in a few tuber generations, the variety is wiped out. Aphis are thought to be the chief agency in

spreading this disease. Roguing and isolation of the seed plot are more effective in controlling spindle tuber than in controlling mosaic. Selection of good-type tubers was found by Werner to give somewhat better yield than did elongated tubers of the same lot; but as a control measure, this was of no permanent value.

III. Physiological Diseases

Certain troubles of the potato are not referrable to specific pathogens and are not infectuous but seem to arise from derangement of physiological functions.

Blackheart.—Though primarily a storage trouble, blackheart may occur also in the field. Affected tubers appear normal on the outside

Fig. 70.—Showing direct tuberization, without vegetative shoots, on sets one month after planting. This condition is sometimes associated with virus diseases, sometimes with physiological conditions.

but when cut, the central pith region is found to be blackened. Or, this tissue may be white at first but, upon exposure to air, turn pink and then black. The discoloration has been shown to be due to the oxidation of tyrosin in cells killed by O_2 deficiency. This deficiency arises through the utilization of O_2 in respiration more rapidly than it can be supplied by diffusion through the outer tissues of the tuber. It generally occurs in tubers stored at rather high temperatures in poorly ventilated containers, freight cars, or storage rooms. A temperature of 38 to 45°C. for 14 to 48 hours will produce blackheart. Affected tubers sprout poorly when used as seed, giving a poor stand, but plants arising from such seed are not necessarily abnormal or diseased.

Internal Browning.—A brownish discoloration of scattered patches of tissue within the tuber is variously referred to as internal brown spot,

heat necrosis, and, in England, sprain. It is of rather common occurrence where potatoes are grown on light, sandy soils and exposed to hot, dry weather. In California, it does not occur where a heavy leaf growth is induced by nitrogenous manures. The shading of the soil, with resultant lower soil temperature, may be more important in controlling the trouble than moisture relations. The trouble is not perpetuated through the tubers, and affected ones may be satisfactory for seed purposes.

Hopper Burn and Tip-burn.—These terms apply to a wilting and rolling inward of the edges of the leaves, which soon become brown and dry. Since the onset of this condition usually coincides with the beginning of hot, dry weather, the ailment has been attributed directly to injury from hot sunshine and dry winds and to the high transpiration with water deficit accompanying these conditions. A true tip-burn, due to these physiological conditions, sometimes occurs, but by far the greater part of the burning formerly called tip-burn, is due to injury by the apple leafhopper (*Empoasca mali*). The leafhopper migrates to the potato plants in great numbers during early summer, punctures the foliage in feeding, and presumably injects a toxin, which causes collapse of the leaf tissues. These insects are repelled by spraying the plants with Bordeaux mixture. Where the trouble occurs, potato plants may be kept alive and great increases in yield secured by protecting the plants in this manner. Varietal susceptibility varies; Bliss Triumph, Early Ohio, Irish Cobbler, and Rural New Yorker is the usual order of resistance.

Insects

Colorado Potato Beetle (*Leptinotarsa decemlineata*).—In states east of the Rockies, the larvae and adult beetles are often extremely destructive to foliage. The adult is ⅜ inch long and yellowish, with five black stripes lengthwise of each wing cover. It is slow moving and generally completes the defoliation of a plant before leaving. Each female may lay 500 to 1,000 eggs. These may be seen in bright-yellow masses on the underside of the leaves; they hatch in about 1 week. The larvae commence feeding at once. They are dull-red, soft-bodied slugs and become as large as adults before entering the soil to pupate. There may be several broods in a growing season. They overwinter as pupae in the soil in waste places near the field. Because of their rapid feeding, adults and larvae are easily controlled with arsenicals, either as dust or liquid spray and applied either alone or in combination with fungicides.

Aphis.—The potato aphis (*Macrosiphum solanifolii*) occurs often on the potato plant, though the green peach-aphis (*Myzus persicae*) and perhaps other aphis, also occur frequently. From the practical point of view, of injury and control, the exact kind of aphis present is immaterial. The potato aphis is often called the pink-and-green plant louse,

because some broods are pink, others green. Overwintering is in the egg stage. The eggs are laid especially on rosebushes, both wild and cultivated; hence, the eradication of roses near potato fields has been suggested. The stem mothers hatch in spring, then migrate to potato plants and produce living asexual females, which reproduce very rapidly. Most of the broods are wingless, but occasional winged broods are produced. At the end of the season, both males and females appear, and eggs are laid which overwinter. The green peach-aphis is rather similar, but egg laying is on peach or plum trees. In the South and in California, aphis may go through the winter as adults, without resorting to egg laying.

The aphis are small, soft-bodied, sucking insects. They adhere closely to the underside of the leaf and often escape notice until the leaf begins to curl or wither. Because of their rapid propagation, control measures should be practiced early. Spraying the roses and the plum and peach trees in the neighborhood, during the dormant season, goes far to eliminate overwintering eggs. Nicotine sprays and dust are effective against the adults during the growing season. While aphis are often numerous enough to cause great direct damage to the plants, they do most injury by transferring virus diseases from plant to plant.

Tuber Moth (*Phthorimaea operculella*).—In the United States, tuber moth is most serious in California, although sporadic outbreaks occur as far east as Maryland. The adult is a small, gray, night-flying moth, having a wing expanse of about ½ inch. It hides under clods or plants during daylight but comes forth toward evening, to oviposit on plants or tubers. Leaves and stems of potato plants are favorite places to deposit eggs, but other solanaceous plants may be utilized. If tubers are exposed, eggs are laid on them. The larvae, hatching from eggs laid on tubers, bore in and, by numerous tunnels, render the tuber unfit for use. They feed for 14 to 69 days, depending upon the temperature, then emerge for pupation. The direct injury to the plant is not serious, but when the insects are numerous, many or all of the tubers may be ruined. Tuber injury is prevented by hilling up in order to cover exposed tubers and close soil cracks; by gathering the tubers promptly in order to prevent infection after digging; and by avoiding contact between potato vines, on which there may be eggs or larvae, and tubers. There may be danger of dissemination of the insect in tubers shipped to market. A system of fumigation with carbon bisulfide, under vacuum, has been devised to eliminate this danger in California.

Leafhopper.—The relation of the apple leafhopper (*Empoasca mali*) to the hopper-burn disease has been discussed. Other kinds of leafhopper may feed on potatoes but do not cause tip-burn. The adult leafhopper is a pale green, slender-bodied insect about ⅛ inch long. As leafhoppers are very active, they are difficult to see unless numerous.

The direct injury caused by them through sucking the plant juices is not important. They may be controlled to some extent with nicotine sprays; but it has been found that the best practical control measure is to keep the plants coated with Bordeaux mixture, which serves as an excellent repellant.

Flea Beetle.—The potato flea beetle (*Epitrix cucumis*) is a small, black, jumping insect about $\frac{1}{16}$ inch long. The adults are omnivorous feeders, attacking many plants, and are particularly injurious early in the season. They eat small holes through the leaves and may skeletonize the latter. Their eggs are laid in the soil, and the larvae may go into the tubers, causing numerous small pimples, somewhat resembling nematode galls. Spraying the plants thoroughly with Bordeaux mixture serves as an excellent repellant.

Nematode.—The potato tuber is very susceptible to injury by the common garden nematode (*Heterodera radicicola*). Seed tubers from sections where this nematode exists should be regarded with suspicion, for planting infected seed introduces the organism into the soil. Seed disinfection does not affect nematodes in galls on the tubers.

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SECTION B. EGGPLANT

Eggplant, sometimes called "Guinea squash," is a truck crop of some importance in Florida and Louisiana and is grown for market on a small scale in some states farther north, especially Virginia and New Jersey. Eggplants have been successfully grown under glass, but the lack of demand when sold at high prices and competition from the winter crop in Florida, Mexico, and California make greenhouse culture unprofitable. The eggplant is little used as a food by American people, except in the South, but is popular with people from southern Europe.

Taxonomy.—The eggplant (*Solanum melongena*) is closely related to the potato and to many native American weeds, such as horse nettle (*S. carolinensis*) and the nightshade (*S. nigrum*). Linnaeus divided eggplants into two species—*S. melongena*, the large fruited edible type, and *S. insanum*, the small-fruited, non-edible form, commonly called "mad apple" in Europe, because of its supposed effect on those who eat it. Nees (1832) considers the latter to be the primitive type of eggplant, hence, united it with *S. melongena*. A species native to Abyssinia, *S. integrifolium*, resembles cultivated eggplant in plant characteristics but has small, lobed, non-edible fruit. Kojima (1925) examined 21 different

races of eggplants and found that all contained the same number of chromosomes, 12 being the haploid and 24, the diploid number. All varieties had chromosomes of the same size and shape.

Bailey (1889) classified eggplants into three sub-species, as follows:

I. Plants tall; leaves large and lobed; fruit large, spherical, or oblong. Var. *esculentum* Nees
   A. Fruit purple: Black Pekin, New York.
   B. Fruit white or striped: White Chinese, Long White, Guadeloupe
II. Plants medium tall; leaves large, angled; fruit very long, slender. Var. *serpentinium* Bailey
   A. Fruit purple: Snake, Long Purple.
III. Plants small, spreading, glabrous, and usually spineless; leaves thin, rounded; fruit small, pear shaped. Var. *depressum* Bailey.
   A. Fruit purple: Early Dwarf Purple, Dwarf Japanese.

Some writers make two general classes of eggplant, depending on the presence or absence of spines. According to Sturtevant, the spiny originated rather recently from the smooth type; both types are found in all varietal groups. Another classification (made prior to 1587) is according to fruit shape, which may be oval, round, long and oblong, or bell shaped.

History.—Eggplant is native to tropical countries of the Old World, India being probably the original habitat, as the plant is still found there in the wild state. The Chinese were among the first to grow it as a vegetable. Arabians of the ninth century were also familiar with it, and it may have been introduced to Europe through the Moorish invaders of Spain. At first, only small, oval fruits were known; they were of diverse colors, and their shape probably suggested the name "eggplant." In spite of the great diversity of varieties which is known in India and China, only one or two have ever been extensively grown in the United States.

Plant Characteristics

The plant is an annual, erect, much branched, and compact in habit of growth, attaining a height of 3 feet in most varieties and 4 to 5 feet in Florida High Bush. The stems are woody. The leaves are large, simple, oval or ovate, somewhat angled or lobed, and tomentose on the underside, except in the variety *depressum*. Stems and leaves and particularly the fleshy calyx lobes are often armed with spines; these are much reduced in size and number in so-called "spineless" varieties.

The flowers are generally solitary and are located on the branches opposite the leaves. They are large and showy, the expanded corolla being 1 to 2 inches in diameter and purple in color. They are formed progressively throughout the growing season. They are hermaphroditic, and the anthers dehisce during the receptive period of the stigma; hence,

self-pollination is prevalent, though considerable crossing may also occur. The anthers form a cone around the style, with the stigma projecting beyond it, and the body of a visiting insect comes in contact with the stigma. Kakizaki (1924) found that the amount of cross-pollination varied from 0.2 per cent to 46.8 per cent in a test with 63 plants, the average being 6.75 per cent. This was determined by planting purple- and white-fruited varieties promiscuously in one field; seed from white-fruited plants which was cross-pollinated gave progeny the following year with the dominant purple fruit color. Flowers emasculated and left to natural pollination rarely set fruit; also, plants grown in a screened house without insects were non-fruitful. On the other hand, Munsen (1892) reports the occasional setting of parthenocarpic fruits from non-pollinated flowers, especially in F_1 hybrid plants. Such fruits contained abortive seed.

The fruit is a pendant, fleshy berry, varying in size, shape, and color. The purple pigment is probably anthocyanin in a thin layer of sub-epidermal cells; dark purple or black, yellowish, striped, and white are the usual colors. The epidermis of the fruit is smooth and is shiny when its slight covering of waxy bloom is rubbed off. The seeds are embedded in the placentae, a spongy mass, which constitutes most of the flesh of the fruit. The fruit contains a bitter substance, probably an alkaloid, which is removed before cooking by soaking thin slices of it in salt water for several hours.

The basal portion of the fruit is partly enclosed by the thick, fleshy, green lobes of the calyx, which become much enlarged during the early stages of fruit development. An abscission zone—a layer of pithy white cells—separates the fruit from the receptacle, but, unless the fruit is injured by fungous diseases or other means, actual separation does not take place until the fruit is physiologically mature, which is long after the edible stage is past. At the apical end of the fruit is a slightly depressed basin, usually marked by a stylar scar. Kosaka (1926) found that the seeds increased in weight and viability as the fruit approached maturity. A similar increase was found in immature fruits after harvesting. This was ascribed to a transfer of nutrients from the flesh to the seed.

Cultural Requirements

Eggplant resembles tomatoes and peppers in its cultural relations but requires higher temperatures for growth.

It is never grown from field planting in the United States, seed always being sown in a hotbed. The plants are rather sensitive to transplanting, and it has been found profitable to take precautions in plant growing, in order to get a well-developed, compact root system, which should not

be injured in transplanting. The use of clay pots or other individual plant containers is favored in growing plants for field setting.

Harvesting and Marketing

The fruit is usually picked when it is about half grown, *i.e.*, it is used in the immature condition. When fully ripened on the plants, it assumes a greenish-bronze color, the flesh becomes dry and tough, and the seed is hard. Harvesting begins with the earliest fruit in midsummer, continuing until the plants are killed by frost. Small pruning shears are used to clip the woody peduncle, leaving the fleshy calyx attached to the fruit.

For shipment, the fruit is wrapped in heavy white paper or each fruit is slipped into a small paper sack. The 60-quart berry crate is used for shipping eggplant in the East; and the large lug box, in California. The principal shipping sections are Florida and Louisiana; these states supply the northern markets during late winter and spring.

Varieties.—The chief variety for all parts of the United States is Black Beauty, a large-fruited, dark-purple variety. The fruits are slightly elongated and should taper toward the stem end.

The New York Spineless variety has fruit somewhat lighter purple in color and more elongated than in Black Beauty.

Florida High Bush is a distinct variety. The plants are relatively tall and slender. The fruit is rather small, ovate, and light purple. In quality of fruit and earliness of maturity, this variety is inferior to those mentioned above; its resistance to the eggplant-blight disease (*Phomopsis vexans*), however, makes it desirable in some parts of the South.

Early Long Purple has a small, weak-growing plant. The fruit is about 2 inches in diameter and 6 inches long.

Breeding

Bailey (1892) made several crosses between white and purple varieties and observed that 22 to 80 per cent of the F_1 plants were non-fruitful. No explanation of the barrenness of these plants has been made, but other investigators have found all varieties to be inter-fertile.

Bailey, as well as Halstead (1903), noted that size and shape of fruit were usually intermediate in eggplant hybrids, with extreme variability in the F_2. Halstead observed apparent dominance of upright habit of growth and of broad leaves over decumbent growth and narrow leaves. In the cross New York Spineless $\times$ Early Long Purple, the F_1 plants matured their fruit much earlier than either parent did. In all eggplant crosses, extreme manifestation of hybrid vigor occurred, the hybrid plants being twice as large as the parental varieties. In size of fruit, the hybrids approached that of the larger parent, and in the cross Dwarf

Purple × Scarlet Chinese, they far exceeded the larger parent in size. In total fruit production, all hybrids far exceeded the more productive parent.

The purple color of the fruit and stems is due to a single genetic factor. Kakizaki (1924) found that the F_1 of a cross of purple × white was always purple, the F_2 segregating into 3 purple:1 white. Halstead (1903) obtained both white and purple in his F_1 progenies, indicating that one of the parents was heterozygous for this factor. Because of the rather large amount of natural cross-pollination in eggplants, commercial varieties are probably heterozygous for many factors, and purification by inbreeding for several generations is a necessary prerequisite for genetic studies.

Diseases

Blight and Fruit Rot (*Phomopsis vexans*).—This is a fungus disease of common occurrence in the South and East, being particularly destructive to plants and fruit in wet seasons. Seedlings are often attacked in the plant bed. In the field, it is most destructive during the latter part of the growing season. Canker-like lesions occur on the lower portions of the stem, the cortex being shrunken and blackened. The plants, partially girdled, grow slowly and produce little fruit. Stem infection of field plants is generally the result of seed-bed infection. On the leaves, a severe spotting occurs, especially on those near the ground, while young leaves at the tips of the stems remain healthy. The leaf spots, small and circular at first, enlarge rapidly under warm, humid conditions, so that the whole leaf turns brown and drops off. On the upper branches of the plant, long, sunken lesions occur, starting usually from a leaf scar. On the fruit, large, sunken, circular, tan-colored areas occur, chiefly near the stem end, often starting beneath the calyx and causing the abscission of the fruit.

Edgerton and Moreland (1921) showed that the fungus is carried over winter by spores on the seed and that the young plants are likely to be infected from this source. The mycelium of the fungus is also found in the seed; hence, disinfection of the seed coat does not eliminate seed transmission. The fungus overwinters in dead plants, which should be burned. Florida Highbush shows considerable resistance. An effective preventative for eggplant blight is to use seed from non-infected fruit and to plant it on land free of this fungus. Edgerton and Moreland found, also, that selection of vigorous and apparently disease-free plants at transplanting time greatly lessened loss from the disease. Spraying the plants with Bordeaux during the growing season serves to check the spread of the disease, but it is not very effective in regions of heavy rainfall. It is necessary to use a sticker to make Bordeaux adhere to the fruit. Edgerton and Moreland found that spraying nine to thirteen times during the growing season increased the yield of sound fruit nearly 100 per cent,

while six applications had little effect. In Virginia, Spencer, *et al.* (1924), obtained large increases in yield from applications of Bordeaux, applied either as a spray or a dust, with the addition of arsenicals. The arsenicals alone, however, were almost as effective; hence, the chief beneficial results in the Virginia experiments may be attributed to insect control and not to control of the Phomopsis blight.

Wilt (*Verticillium albo-atrum*).—This wilt disease is common on eggplants in New Jersey and in the cool coastal regions of California, but it is not important in the warmer parts of the country. The fungus can probably persist in the soil indefinitely, because of its extensive host range. It is also distributed in manure and in plants from infected plant beds, but according to Haenseler (1922), it is not transmitted through the seed. The characteristics of wilt are similar to those described under tomato (see p. 328). Stunting of the plants and nonproductivity are often the only striking effects.

Insects

Eggplant is attacked by the same species of insects as is potato and especially by flea beetles, aphids, and Colorado potato beetles. These are discussed in the chapter on potato (see p. 390). Young plants may be protected against flea beetles by dipping the entire plant, except the roots, in Bordeaux at transplanting time. When the plants begin to put out new leaves, these are protected by spraying with Bordeaux. Bordeaux serves as a repellent to flea beetles but is more effective if arsenicals are added.

Red Spider (*Tetranycleus* spp.).—These are extremely small reddish or yellowish mites, which occur, especially on the underside of the leaves, in periods of very dry weather. Since the eggplant is not particularly sensitive to S, this insect may be controlled by dusting with a mixture of equal parts of ground sulphur and lime. Soluble-oil sprays are also effective.

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PART XI

CUCURBITACEAE

From the phylogenetic point of view, the *Cucurbitaceae* are usually placed among the *Sympetalae*. Vuillemin (1923), however, would place them in the *Apetalae*, on the ground that the petaloid parts, usually considered to be the corolla, really constitute an inner whorl of the calyx.

The first general review of *Cucurbitaceae* was made by De Candolle (1828), who lists 80 genera containing 601 species, of which 288 are attributed to the Old World and 313, to America. Only three genera contain species important as food plants, though others are used as ornamentals, medicinally, or for the manufacture of insecticides (Bryonia).

The cultivated members resemble each other in general appearance, have similar climatic and cultural requirements, and are subject to attack by the same insects and diseases. Of the six cultivated species, interspecific hybrids have never been obtained, despite numerous efforts, especially by Bailey (1890), Pammel (1892), Lotsy (1920), and Vavilov (1925). Vavilov found that the genera of cultivated *Cucurbitaceae* differ in the character of their pollen and in chromosome number. On the other hand, some fruit and foliage characteristics are common to certain varieties of different species, and this fact has been erroneously taken as evidence of hybridization.

The chromosome numbers of the cultivated *Cucurbitaceae* are as follows, according to Koslukkow (1925):

	Pairs
Cucumis sativus (cucumber)	7
Cucumis melo (melons)	12
Citrullus vulgaris (watermelon)	11
Cucurbita pepo (bush squash, pumpkin)	20
(12, according to Lundegardh)	
Cucurbita maxima (winter squash)	24
(20, according to Castetter)	
Cucurbita moschata (Cushaw squash)	24

Other chromosome numbers in the *Cucurbitaceae* are: *Micrampelis lobata*, 16 pairs; *Bryonia alba*, 10, and *B. diocia*, 12. The chromosome numbers in *Cucurbitaceae* do not form a polyploid series as in some other families.

CHAPTER XXI

CUCUMIS

De Candolle lists in the genus *Cucumis* 26 species, of which 5 are native to India; 3 to North Africa; 16 to Central Africa; 9 to South Africa; and 1 to tropical America. The species generally cultivated are *C. melo* and *C. sativus*. Members of the former are designated by the general term "melon;" and the latter, by the general term "cucumber." The immature fruits of cucumbers bear warts, surmounted by spines, or trichomes; the latter are lacking in melons. The pollen of melons is round; of cucumbers, tetrahedral.

SECTION A. MELONS

Taxonomy.—Within the species *C. melo* are included many diverse forms, which Naudin (1859) classified into sub-species, as follows:

1. Var. *reticulatus*.—Netted, or nutmeg, melons. This includes most American varieties of "cantaloupe." The fruit has a netted skin and shallow sutures and ribs, and its flesh varies from light green to reddish orange in color.

2. Var. *cantaloupensis*.—European cantaloupe melons, rock melons. The fruits are not netted but are warty, scaly, or rough and have a hard rind. Not grown in America.

3. Var. *saccharinus*.—Pineapple melons, sucrins. Oblong, netted melons, having a tender flesh. This group merges into group 1.

4. Var. *flexuosus* (*C. flexuosus L.*).—Snake melon, serpent cucumber. Long, slender, crooked, non-netted fruits. Inedible.

5. Var. *inodorus*.—Winter melons. Fruits lack musky odor, have a smooth or a ridged skin, are not netted, ripen late, and keep well. Honey Dew, Casaba.

6. Var. *acidulus*.—Cucumber melon. Inedible.

7. Var. *chito* (*C. chito*, Morr.).—Garden lemon, vegetable orange. The small, numerous fruits are used to some extent for making preserves. Generally confused with group 6.

8. Var. *dudaim* (*C. dudaim* L. and *C. odoratissimus* Moench.).—Pomegranate melon, Queen Anne's Pocket melon. Small, round, highly-scented fruits. Inedible.

Besides the eight groups considered by Naudin, the Persian or Armenian melon, grown extensively in California, may be considered as distinct, though in general conforming to the *reticulatus* group. A tenth group is

C. melo var. *cocomon*, the Oriental pickling melon, formerly considered a separate species.

The term "cantaloupe" was applied originally to a variety grown at the castle Cantaloupo, near Rome. Naudin used it as a general name for

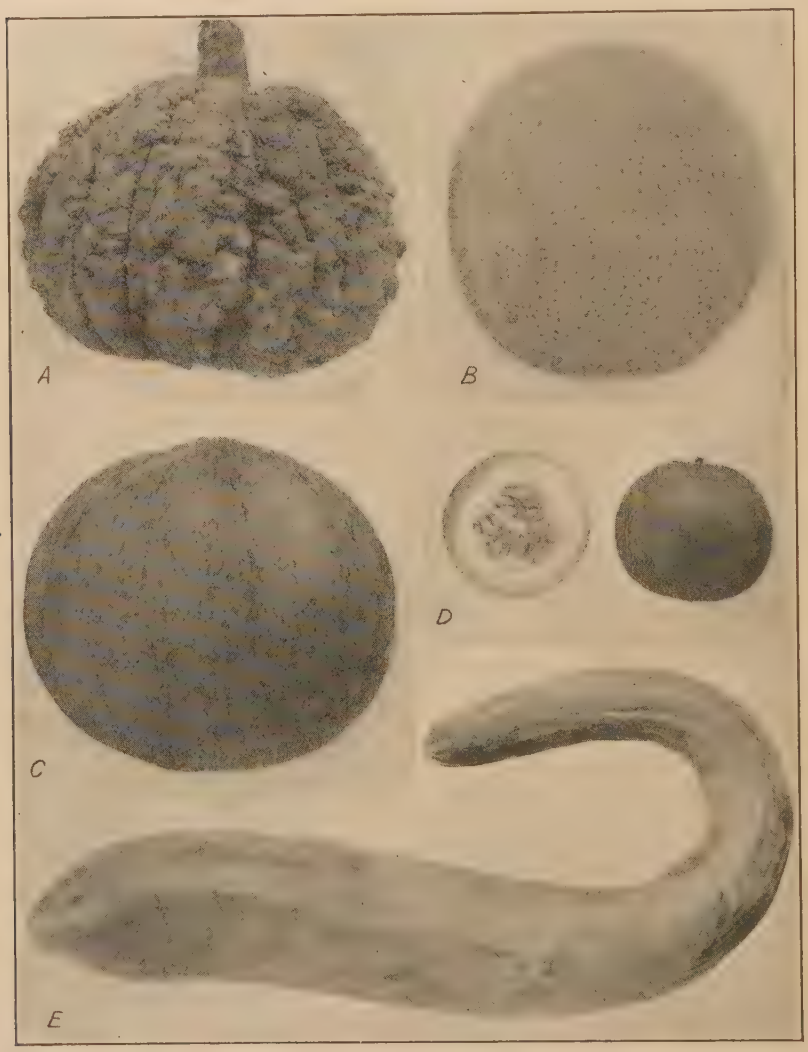

FIG. 71.—Botanical varieties of *Cucumis melo*. A. var. *cantaloupensis*, the European cantaloupe. B. var. *reticulatus*, the netted melon or American cantaloupe. C. var. *inodorus*, the winter melon (casaba). D. var. *acidulus*, the mango or garden lemon. E. var. *flexuosus*, the snake melon.

the warty-fruited melons, which, in Europe, are still called "canteloupe melons." In the United States, however, this term has come to be applied to the netted melons. Large-fruited cantaloupes are often

referred to as "muskmelons," on account of the aroma of the ripe fruit. In this text, the term "melon" is used for all varieties of *C. melo*.

History.—Melons are supposed to have been indigenous to India. Wild forms, *C. agrestis* Ndn. and *C. trigonus* Roxb., are found in central and southern Asia, and Pangalo (1925) concluded that the latter crossed with *C. melo*, though with difficulty. The ancient Egyptians and the Greeks and Romans had several varieties. Many diverse forms of melons, few of which are known in America, are grown in Oriental countries. Some of the American varieties originated from importations through Europe; others (Casaba and Persian) have come from Asia Minor. Melons have been grown in America since Colonial times, but the extensive commercial culture of this vegetable is of comparatively recent development. The history of commercial melon culture in this country is almost a history of the Rocky Ford strains. These have been developed in Colorado from Netted Gem, a variety introduced from France by W. A. Burpee, of Philadelphia, in about 1880. Prior to 1895, cities were supplied for a few weeks in summer with locally grown melons of varying types and sizes, which often lacked quality and uniformity and were generally too large and soft to ship. With improved varieties and better transportation and refrigeration, culture and popularity of melons have increased rapidly. The season of use now extends from May to October.

Plant Characteristics

The root system consists of a rather short, thick tap-root, which sends out several laterals 6 to 8 inches below the surface of the soil. These grow outward and downward for several feet and are well supplied with fibrous roots.

The plant is a hirsute, trailing annual. The stems may attain a length of 8 to 10 feet. From the lower leaf-axils arise four or five primary branches, which nearly equal the central stem in their development. From these, several secondary branches arise. On the primary and secondary branches and on the central axis arise the short, fruiting branches. The stems, herbaceous at first, become woody with age and are characterized by very extensive development of the conductive tissues. The sieve tubes have been especially studied by Fischer (1884); and the vascular anatomy, in general, by Worsdall (1916).

The leaves are alternate, simple, palmately five-lobed, and somewhat angled when young but become sub-cordate when full grown. Non-forked tendrils are borne opposite the leaves. According to Frinkgeld (1923), these are transformed leaves, whereas in other cucurbits, the lower, non-sensitive portion, or tendril bearer, is stemlike in structure, and the upper portion corresponds to a terminal leaf.

Flowers.—All varieties of melons fall, with reference to their flower structure, into two groups. Most American varieties are andromonoecious, bearing staminate and hermaphroditic flowers. Many European varieties are monoecious, bearing staminate and pistillate flowers.

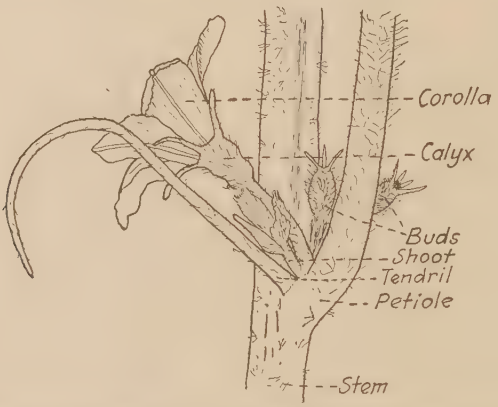

FIG. 72.—The staminate inflorescence of a melon plant, showing a staminate flower and several male buds.

FIG. 73.—A fruiting branch of a melon, showing the first and second hermaphroditic flowers.

The staminate flowers are borne in axillary clusters of three to five on all the stems of the plant except the axils occupied by the hermaphroditic flowers. The calyx tube is turbinate or campanulate and is five lobed. The large, yellow corolla is campanulate, with the upper portion

expanded in five or six lobes. The stamens are inserted on the base of the corolla. Vuillemin (1923) shows that the androecium consisted originally of two whorls of three stamens each but that, through the abortion of one, it is now represented by a single whorl of five stamens. In most varieties, two pairs are united, so that the flowers have two double stamens and a single one. The anthers of the double stamens assume the shape of an M. The staminate flowers are far more numerous than the pistillate and hermaphroditic ones, appear 2 weeks earlier, and continue to appear later in the growing season.

The hermaphroditic flowers are borne singly in the first and second axils of the fruiting branches. The latter may elongate and later produce

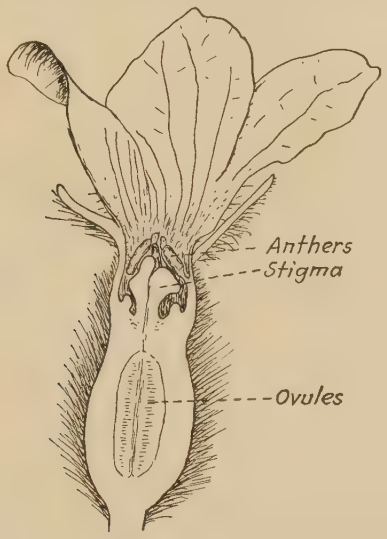

FIG. 74.—A section through a hermaphroditic flower of a melon.

numerous staminate flowers but never produce more than two hermaphroditic flowers. The thick, fleshy ovary is divided by longitudinal walls into three, four, or five locules, each of which contains several longitudinal rows of ovules. The ovary is surmounted by a calyx and a corolla bearing a whorl of stamens similar to those of the staminate flowers. The short, thick style is capped by a lobed stigma, the divisions of which correspond to the locules of the ovary. At the base of the style are the nectaries, which secrete considerable nectar, most attractive to bees.

Pistillate are similar to hermaphroditic flowers, except that the stamens are absent or rudimentary.

Pollination.—The flowers open about 2 hours after sunrise and close in the afternoon of the same day. By the following morning, the corolla is withered. The anthers dehisce soon after the corolla is fully open.

Dehiscence is by longitudinal splitting of the anther lobes, but the pollen is not forcibly expelled, remaining in masses in the open pollen sacs. Zimmerman (1922) states that the pollen of nearly all *Cucurbitaceae* is covered with an oily film, which explains the pollen's sticking in the anthers. The stigma is receptive from 1 day before until the afternoon of the day of anthesis. In the individual flower, anther dehiscence, nectar secretion, and receptivity of the stigma occur concurrently but for only a portion of 1 day.

The hermaphroditic flowers are self-fertile, but Rosa (1924) found that self-pollination is not likely to occur, unless the flowers are visited by

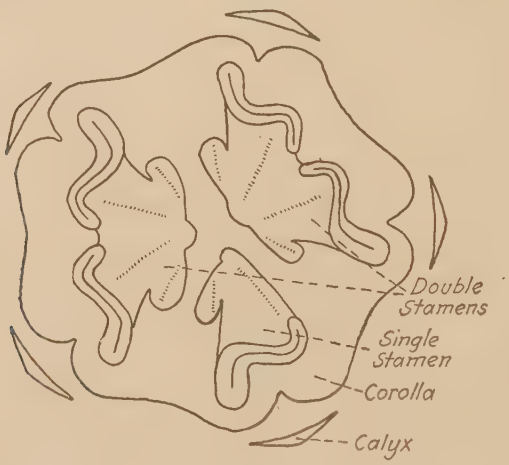

FIG. 75.—Floral diagram of a pentamerous staminate melon flower. (*After Vuillemin.*)

insects or pollinated by hand. This is because of the stickiness of the pollen. Honeybees are the most frequent visitors. Since the flowers are chiefly insect-pollinated, the presence of bees in the field is necessary for fruit setting. In reaching for the nectar, the bees scatter pollen from the anthers to the stigmatic surface, thus effecting self-pollination. They also carry away some pollen, which may be dropped onto the stigma of another flower on another plant, thus effecting cross-pollination. From 5 to 15 per cent of the seed of hermaphroditic-flowered varieties may be cross-fertilized, where different varieties are grown in adjoining rows.

From the genetic point of view, autogamous self-pollination of hermaphroditic flowers is the same as the application of pollen from staminate flowers of the same plant, or geitonogamy. In varieties having pistillate flowers, the latter is the regular mode of pollination. In such varieties, a high percentage of cross-pollination with other plants is likely to occur. For fruit development, the mode of pollination makes no differ-

ence. All varieties of melons are capable of self-fertilization, and all the types included in the species *C. melo* are interfertile.

Fruiting Habit.—The hermaphroditic, or pistillate, flowers, which determine the location of the fruit, are formed only in the first and second leaf-axils of the fruiting branches. Most of them degenerate soon after or even before anthesis. The ovary in the first axil on a fruiting branch has a better chance to develop than that in the second one. Rosa (1924) found that there are definite fruiting cycles. One or two flowers, on the basal fruiting branches of each stem, have a good chance of setting fruit. Fruits which form near the base of the various stems are called the "crown set." After one or two develop on a stem, the ovaries of all flowers formed on the next eight or ten fruiting branches of that stem will abort. Then may ensue a second setting period, wherein one or two

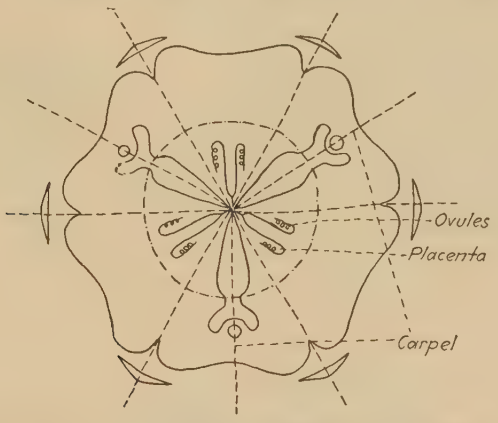

FIG. 76.—Floral diagram of a hexamerous pistillate melon flower. (*After Vuillemin.*)

fruits may form, followed by a second period of sterility. During the periods of non-fruit setting, the development of the fruiting branches is much reduced. Nipping the terminal bud of main branches at a certain time may increase the growth of the fruiting branches and hasten a second setting period. Lloyd (1920) has shown, however, that nipping the vines when 1 foot long has little effect on the development of the crown set of fruits, either as to time of maturity or number produced.

Fruit.—The fruit is a fleshy berry, or pepo, the outer portion being receptacle fused with the pericarp.

Fruits vary in size, according to the variety. In shape, they may be oblate, spherical, oval, or elongate. In most varieties, there are ten longitudinal grooves, or sutures, with ribs between. In some varieties, the sutures and ribs are entirely lacking. The surface of the immature fruit is generally green, becoming yellow or reddish upon maturity. Toward maturity, the surface may be covered more or less densely with

a network of grey, corklike, heavily suberized tissue. In the young fruit, rapidly dividing cork cells are found below the epicarp, and as the fruit matures, this growth breaks through to form the netting. Miss Barber (1909) finds that this tissue consists of small, thin-walled cells, radially arranged, which, together with the ruptured epicarp, somewhat

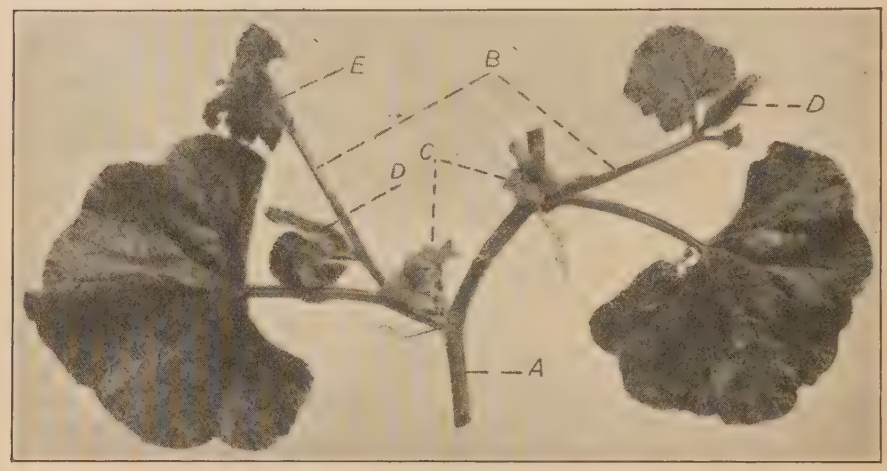

Fig. 77.—Showing the floral arrangement in a portion of a melon plant. A. Main axis or primary lateral. B. Fruiting branches. C. Staminate inflorescences. D. Hermaphroditic flowers on first node. E. Hermaphroditic flower on second node of fruiting branch.

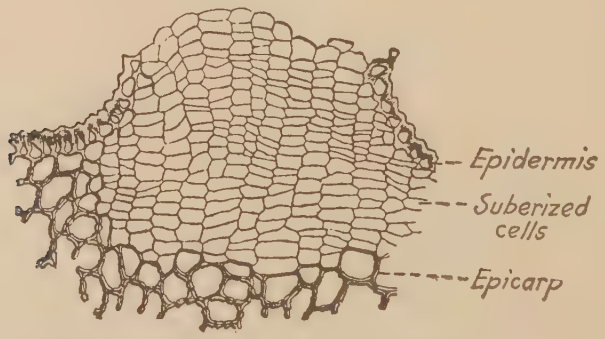

Fig. 78.—Section through a rib of the net, of a netted melon. (*After Barber.*)

resemble lenticels. Stomata are present in the sutures and between the corky ridges of the net.

The fruit wall consists of four to six layers. Outermost is the epicarp, or exocarp, which includes the epidermis and the hypoderm. The epidermis is a single layer of colorless cells, varying in size, shape, and thickness of walls. On the ribs, these form a palisade layer of greatly thickened, polygonal cells with cutinized walls; but in the sutures, the

cells are larger, thinner walled, and pitted. The hypoderm consists of several rows of rounded, thickened cells; it constitutes most of the rind.

Chlorophyll is present in the hypodermal cells, though sometimes masked by a yellow pigment. Within this is the mesocarp, the fleshy part of the fruit, consisting of undifferentiated parenchyma cells. This layer is traversed by the vascular bundles and by the isolated sieve and latex tubes. Sometimes these elements are developed to such an extent as to give an undesirable fibrous texture to the flesh. In some varieties, the mesocarp is rather distinctly divided into outer, middle, and inner layers. The innermost layer of the fruit wall is the endocarp, a thin, transparent layer of elongated, thin-walled cells, bordering the cavity.

The central cavity during early growth of the fruit is filled by the placenta and the developing seed. As the fruit grows, the cavity becomes larger, and an open space is left in the center and between the locules.

At Davis, California, in the Salmon Tint variety, from 42 to 46 days elapse between the fertilization and maturity of fruit. Gustafson (1926) shows that the growth of melon fruit follows a typical *S* curve, approaching a maximum weight at 40 days after setting, with little increase the last few days before ripening. During the latter part of fruit development, important maturation processes take place, especially regarding the accumulation of sugars.

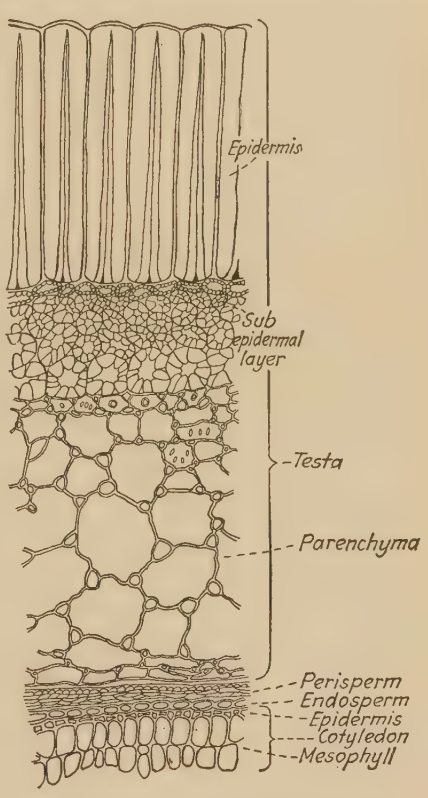

FIG. 79.—Section through the covering of a mature melon seed. (*After Harz.*)

Seed.—Each fruit produces from 400 to 600 seeds. A seed is 2 to 3 millimeters long, ovate, and flattened. It possesses two coats, described by von Hohnel (1896). The embryo is enclosed within five distinct tissues: (1) outside a thin, gelatinous, epithelial layer, noticeable only when the seeds are wet; (2) outer seed coat, a layer of schlerenchymatized cells, eight to ten deep; (3) inner seed coat, a thin, membranous tissue, consisting of three or four layers of collapsed, thin-walled cells; (4) perisperm, a thin layer of collapsed cells derived from the nucellus;

(5) endosperm, consisting of one layer of thick-walled, polygonal cells, containing oil and protein granules. During the development of the seeds, the endosperm contains starch, which disappears upon maturation. In the embryo, the cotyledons are large and well developed and contain some reserve food.

Climatic and Soil Requirements

Melons require a frost-free growing season. Warm nights with hot days favor the best development. As the growing season, however, is comparatively short, some varieties may be grown outdoors in nearly all parts of the United States. In England, melons are grown in greenhouses or in frames, as there is not sufficient heat to mature the fruit in the open. Rauchenstein (1927) shows that the ripening season in Imperial Valley, Calif., begins when the accumulated mean temperatures above 10°C., from Jan. 1, total 1,110°C. Though the actual date has varied as much as 34 days over a 14-year period, the heat accumulation in any one year has not varied markedly from the average.

Environmental factors have a marked effect upon development and quality of fruit. Low relative humidity of the air during ripening favors development of the thick, coarse netting and the solid fruit flesh. These characteristics are necessary for good shipping quality. Low humidity, coupled with absence of rain, prevents fungus diseases, which often defoliate the plants in humid sections unless carefully sprayed. Premature defoliation lowers yield, shortens the picking season, and impairs the quality of the fruit. The maximum amount of sunshine produces high sugar content, solidity, and fine flavor. Thus, the arid climate of the Southwest partly explains the development of extensive cantaloupe production there.

Muck, or peat, is never used for melons, and heavy clay and adobe soils are generally avoided. The crop is grown most extensively on sandy or sandy-loam soils. Fairly heavy loams and silts also often give good results.

Soil should be well supplied with organic matter, fairly fertile, and free from nematodes, wilt disease, and toxic amounts of alkali. While not tolerant of a high concentration of soluble salts, melons thrive best on soils slightly alkaline or neutral in reaction. Hartwell (1914) showed that melons belong to the class of plants benefited most by applications of lime to acid soils.

Wilkins (1917) found that stems and leaves of melons and other cucurbits have an unusually high Ca content. The percentages of all constituents except Ca decrease rapidly as the vines become older, though the total amount of minerals in the whole plant continues to increase until maturity.

TABLE 66.—NUTRIENT ELEMENTS IN MELONS
(*Wilkins*, 1917)

	As per cent of dry matter					
Stems and leaves	Dry matter	Nitrogen	Phosphoric acid	Potassium oxide	Calcium oxide	Manganese oxide
July 21	9.7	3.98	0.75	4.43	6.12	0.78
Sept. 13	45.6	2.11	0.40	2.89	5.67	0.72
Fruit (ripe)						
Flesh	10.2	1.78	0.67	4.22	0.73	0.43
Seed	14.1	3.21	1.21	4.40	0.15	0.58

The amount of some nutrient elements removed by a crop in New Jersey is given as follows, in pounds per acre:

TABLE 67.—TOTAL AMOUNT OF NUTRIENTS IN A CROP OF MELONS, IN POUNDS TO 1 ACRE
(*Wilkins*, 1917)

	Green weight, pounds	Dry weight, pounds	Nitrogen	Phosphoric acid	Potassium oxide	Calcium oxide	Manganese oxide
Vines	3,132	939	19.8	3.8	28.2	53.3	6.8
Fruit flesh	11,310	1,154	20.5	7.7	48.7	8.4	5.0
Seed	2,175	307	9.8	3.9	13.5	0.5	1.8
Total	16,617	2,400	50.2	15.4	90.3	62.2	13.5

The large amounts of N and K removed by the crop are worthy of note. Since Ca increases in the vines toward maturity and is very low in the ripe fruit, it may be that, during ripening, there is a translocation of Ca from the fruit to the vines. This process may be connected with changes in the pectic compounds of the middle lamella of fruit cells and cause softening of the flesh and abscission of the fruit.

CULTURAL PRACTICES

Planting Date.—The planting date for a given locality depends upon weather conditions. Part of the crop is planted earlier than the average date, to obtain the advantage of the early market. Table 68 shows approximate planting dates for different sections.

TABLE 68.—SHIPPING DATES FOR CANTALOUPES

Imperial Valley, Calif.	Dec. 1 to Mar. 15	Moapa, Nev.	Apr. 1 to 15
Brownsville, Tex.	Feb. 10 to 20	Dover, Del.	Apr. 5 to 20
Turlock, Calif.	Mar. 15 to Apr. 15	Anna, Ill.	Apr. 5 to 15
Blackville, S. C.	Apr. 1 to 15	Yakima, Wash.	Apr. 20 to May 1
Bolton, Ark.	Apr. 1 to 20	Medford, Ore.	Apr. 10 to May 1
Glendale, Ariz.	Apr. 1 to 20	Rocky Ford, Colo.	May 1 to June 1
Decker, Ind.	Apr. 1 (in hotbed)	Grand Rapids, Mich.	May 20 to June 10

Germination.—All of the layers surrounding the embryo are permeable to air and water. The embryo does not possess a true rest period, for germination takes place whenever proper conditions are provided. At high temperatures, the seed may germinate in the fruit before it is fully mature.

Swelling, as a result of the absorption of water, splits the seed coats, especially at the micropylar end. The radicle, already well developed in the mature seed, emerges first, turning downward to form the permanent tap-root of the plant. The rapidly elongating hypocotyl withdraws in the form of an arch, which grows upward, until the surface of the soil is reached. When through the soil, growth becomes slower on the upper side of the arch, causing the hypocotyl to straighten and eventually pull-

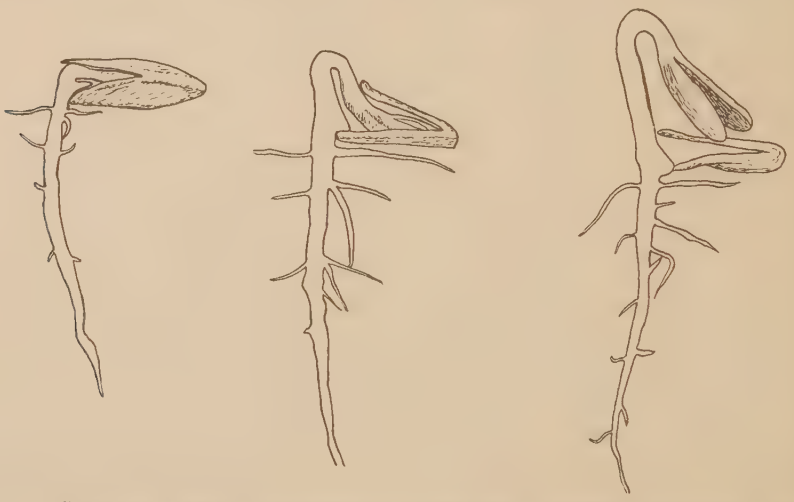

FIG. 80.—Successive stages in germination of melon seed, showing the function of the peg in removal of the seed coat. (*After Crocker, et al.*)

ing the cotyledons, now freed from seed coats, to the surface. A structure, known as the "peg," develops on the hypocotyl in the early stages of germination and holds the seed coats in place while the cotyledons are being withdrawn. Crocker, *et al.* (1910), showed that the peg develops during germination in the form of a ring encircling the hypocotyl and becomes especially developed on one side as a result of the arching growth of the hypocotyl and the stimulus of contact with the seed coat.

Melon seed germinates within 48 hours, in the presence of moisture and air, at 30°C. Speed of germination decreases with temperature; there is no germination at temperatures below 10°C. This is a reason for delay in field planting, until the soil is warm enough for speedy germination. Freshly harvested seed should give a 95 per cent germination under laboratory conditions. Viability is retained for 8 or 10 years in dry, cool storage.

Some growers believe that old seed produces a better crop than new seed does and that the latter produces excessive vegetative growth. Tests by Bailey (1889) show no basis for this belief, however. Seeds from 1 to 6 years old, of several varieties of melons and other cucurbits, showed no consistent relation between age, fruitfulness, and vegetative growth.

Preparation for Planting.—Two methods are used—planting by hand in hills, and drilling in rows with a seeder. Under irrigation, beds are made and are irrigated once before planting. The seeds are sown just above the water-mark on the south side of the bed. During the growing season, the vines are turned so that they are kept on the bed, above the water-line. Developing fruit must rest on dry soil. The furrow between the beds carries the water, which seeps through the soil to the roots. In some districts, where the natural moisture supply is sufficient to start the plants and where few subsequent irrigations are needed, beds are not used. The field is prepared level and the seed drilled in rows; irrigation furrows are opened later between them.

In regions of summer rainfall, the field is laid off in checked rows, and seed is planted in hills at the intersections.

Planting Distance.—Where the planting is in checked rows, the hills are usually 6 by 6 feet, with several plants in each hill. Fulton (1902) found that two plants per hill gave more fruit than one, three, or four plants. His results were as follows, from rows 200 feet long:

	Average Weight per Fruit, Pounds
One plant per hill, 90 marketable and 19 small	1.09
Two plants per hill, 116 marketable and 30 small	0.98
Three plants per hill, 86 marketable and 27 small	0.99
Four plants per hill, 47 marketable and 57 small	0.79

When the seeds are drilled, the rows are usually 6 feet apart, and the plants are thinned to 2 feet apart. This method gives more plants per acre and larger yields but is not as convenient for horse cultivation as is checked-row planting.

Transplanting.—An early crop is obtained by starting the plants in a hotbed or greenhouse. They are started in pots and transferred to the field without disturbing the root system. This practice is profitable in the North. Walker (1901) found that the transplanting method advanced maturity but gave lower yield and smaller melons.

Melon plants are transplanted with difficulty, except when very young. Loomis (1924) showed that melons and other cucurbits are difficult to transplant, because they form new roots slowly. The roots develop a suberized layer at an early age, rendering them ineffective for direct absorption of water and retarding the formation of new roots.

TABLE 69.—YIELD OF TRANSPLANTED AND FIELD-SOWN MELONS
(*After Walker*)

	Fruit ripe	Average number of melons per hill	Average weight, ounces
Transplanted, sowed Apr. 18	July 17	7.11	21
Not transplanted, sowed May 13	Aug. 2	8.43	31

Plant Protectors.—Paper covers are used in California to protect the early crop. Squares of oiled paper, 18 by 18 inches in size, are supported over the hill on wire arches placed at right angles. The edges of the paper are weighted down with soil. After the plants have developed four or five leaves, the paper is raised on the south side, and later it is removed entirely. Another device consists of a machine-pressed, paraffined paper cone, which is rigid enough to support itself. These protectors raise the temperature of the soil several degrees, so that germination is secured during the cool winter months. They also protect the plants from frost.

HARVESTING

For local use, melons are harvested when the abscission zone develops, separating fruit from stem. Melons intended for shipment should be picked when of good eating quality yet firm enough to stand shipment. To some extent, these qualities are opposed, for the highest quality is developed when the fruit matures on the plant, but this stage is accompanied by softening, which makes the fruit unfit for long shipment. Difference in varieties, time of season, and weather conditions have to be considered as well as the distance which melons are to be shipped.

The Ripening Process.—Certain external indications of maturity may be observed. The net becomes fully developed all over the fruit, well raised above the skin, and rounded at the surface. In immature fruit, the netting is flat and has a slight crease along the top. Though little of the skin is visible in the heavily netted types a change from dark green or gray green to yellowish is indicative of maturity. As ripening advances, a crack develops around the peduncle, at the base of the fruit. When ripe, the fruit slips easily from the stem; this is the "full-slip" condition. "Half slip" is the stage in which only part of the stem slips cleanly when the fruit is forced off.

Chase, Church, and Denny (1924) showed that the soluble solids, the sucrose content, and the refractive index of the juice increase as the melons ripen and that the starch content of the seed decreases. These workers studied the relation of composition to external indications of maturity and to edible quality. Edibility depends on texture, flavor,

and sweetness. Sugar content is the most important factor; it may be estimated by determining the soluble solids in the juice of the edible portion. The refractive index is the degree of refraction of a beam of light passing through a liquid; it increases with the density of the solution. The method usually used is to measure, with a hydrometer the specific gravity of the juice. Several fruit are cut, seed and placenta are removed, and the edible portion is spooned out and passed through a food chopper. The juice is squeezed out through cheesecloth, placed in a tall cylinder, and allowed to stand for 5 minutes. Then a spindle hydrometer, graduated in degrees Brix, is placed in the juice, and the top reading is taken and corrected for temperature. Degrees Brix correspond to per cent of soluble solids calculated as cane sugar. Table 70 gives a summary of the results obtained on a large number of samples of the Salmon Tint variety.

TABLE 70.—RELATION OF MATURITY OF MELONS, AS INDICATED BY STEM ABSCISSION, TO PER CENT OF SOLUBLE SOLIDS IN JUICE
(*Chase, Church, and Denny*, 1924)

Place	Stage of maturity			
	Field ripe, per cent	Full slip, per cent	Half slip, per cent	Immature, per cent
Turlock, California, 1916	11.6	11.9	11.9	9.5
Brawley, California, 1916	12.6	13.1	12.4	10.7
Brawley, California, 1917	....	13.8	13.3	
Garden Grove, California, 1917	....	11.9	10.7	

It is clear that immature melons are lower in soluble solids than are those more mature. Soluble solids, however, increase only slightly in melons passing from half-slip to full-slip stage, and in the field ripe, *i.e.* soft, yellow, melons, are lower than melons in full slip. The rapid respiration of fruit ripening in the field uses up some of the sugars. The slight differences found between half- and full-slip melons show that stem abscission is not a reliable index for determining small differences in maturity. Frequently, full-slip melons are really more immature from the standpoint of composition and edibility than are those picked on the half slip.

Church, *et al.*, found that melons could not be picked satisfactorily on the basis of color of skin, for a third of the melons having dark-green skins had the composition of mature melons of good quality. While they found some correlation between maturity and disappearance of the crease on top of the net, 50 per cent of the melons showing a faint line were edible. Only 15 per cent of the melons with a distinct line on the

net were ripe enough to ship, however. The crease on the net is a useful guide to graders and inspectors. Concerning the extent of the netting, 16 per cent of the fruit having a well-developed net were inedible, while 46 per cent of the sparsely netted melons were unfit to eat. Apparently, no external indication is infallible in determining the proper stage for picking melons for shipment.

Chase, *et al.*, determined quantitatively sugar content in the juice of melons picked at different stages of maturity. Table 71 gives a summary of their analyses.

TABLE 71.—SUGAR CONTENT IN JUICE OF MELONS PICKED AT DIFFERENT STAGES OF RIPENESS, ACCORDING TO STEM ABSCISSION
(*Chase, Church, and Denny*, 1924)

	Stage of maturity			
	Field ripe	Full slip	Half slip	Immature
Turlock, Califorina:				
Sucrose, per cent	5.76	5.57	5.43	3.05
Total sugar, per cent	8.78	8.63	8.76	7.00
Brawley, Califorina:				
Sucrose, per cent	7.43	6.76	5.45	3.84
Total sugar, per cent	9.85	9.53	8.67	

Sugar content shows about the same relation to maturity as did soluble solids. Immature fruit is relatively low in sucrose and total sugars, while the differences between the other classes are small. Rosa (1926*B*) showed that sucrose increases during ripening partly at the expense of the reducing sugars.

In a study of ripening in the Salmon Tint variety at Davis, California, flowers were tagged, and some of the fruits were picked at intervals during the later period of development. Table 72 gives the analyses of composite samples of the flesh of fruits of known age. (Chase, *et al.*, analyzed the juice of samples picked at different stages.)

Total solids (per cent of dry matter), sucrose and total sugar content of the flesh, and the specific gravity of the juice increase steadily during maturation, while reducing sugars and polysaccharides decrease. Nearly half of the total solids in the mature fruit is sucrose. There is no extensive reserve of starch or hemicellulose, a fact which explains the absence of any increase in sugar after picking. There is, in fact, a decrease of sugar during storage, due to losses by respiration. Twelve days before the full-slip stage is reached, the fruits are barely edible and the juice is above the legal minimum specific gravity for shipping.

TABLE 72.—CHANGES IN COMPOSITION OF MELONS DURING GROWTH, RIPENING, AND STORAGE, IN PER CENT OF FRESH WEIGHT OF FLESH
(*Rosa*, 1926*B*)

Time sampled	Condition of fruit	Total solids, per cent	Brix reading on juice	Reducing sugars	Sucrose	Total sugar	Polysaccharides
Twenty-five days after setting	Inedible, flesh white	6.00	5.9	2.92	0.19	3.12	0.527
Twenty-eight days after setting	Inedible, flesh faint pink	7.25	7.1	3.28	0.80	4.14	0.513
Thirty-one days after setting	Barely edible, flesh medium pink	9.70	9.3	3.20	2.61	6.01	0.504
Thirty-four days after setting	Edible, flesh pink	9.82	9.6	3.10	3.05	6.27	0.480
Thirty-seven days after setting	Edible, flesh pink	10.74	10.8	2.74	4.17	7.22	0.446
Forty days after setting	Forced slip	12.19	11.5	2.43	5.19	8.02	0.323
Forty-three days after setting	Full slip	12.16	11.8	1.97	5.43	7.81	0.283
Forced slip melons stored 10 days at 3°C		11.26	11.4	2.40	4.82	7.66	0.263
Same, after 3 days at 23°C		12.4	11.5	2.45	4.35	7.14	0.236

Relation of Composition to Edibility.—It has been shown that soluble solids and sugar content increase with maturity, as indicated by the slipping of the stem. This index of maturity, however, is not always reliable in separating high-quality fruit from fruit of poor quality. Chase, *et al.* (1924), determined the relation between composition and quality, as determined by taste. Table 73 gives the averages of many analyses of the juice of Salmon Tint melons.

TABLE 73.—RELATION OF COMPOSITION OF JUICE OF MELONS TO EATING QUALITY
(*Chase, Church, and Denny*, 1924)

	Quality of fruits as determined by tasting			
	High quality	Satisfactory	Doubtful	Inedible
Tulare, California:				
Refractive index, degrees	63.0	58.5	54.0	45.5
Soluble solids, per cent	12.0	11.0	10.0	7.9
Sucrose, per cent	6.58	5.29	4.13	2.04
Turlock, California:				
Refractive index, degrees	60.5	57.08	49.9	45.0
Soluble solids, per cent	11.6	11.0	9.1	7.7
Sucrose, per cent	6.12	5.39	3.55	1.77
Brawley, California:				
Refractive index, degrees	60.0	58.7	50.7	44.6
Soluble solids, degrees	12.3	11.9	10.1	8.6

There is a regular increase of the refractive index, soluble solids, and sucrose from inedible (immature) to high-quality fruit. The difference between the various classes of fruit is much more striking when determined by tasting than when maturity was judged only by the slipping of the stem. In the marketing of melons, maturity is a consideration only in so far as it is connected with eating and shipping quality. Composition seems to be the only criterion for determining what melons are fit to ship. Chase, *et al.*, concluded that melons containing 10 per cent soluble solids, or more, were almost certain to be of good quality, while melons having 9 per cent soluble solids, or less, are unfit to market. The latter has been taken as the minimum allowed under the Fruit and Vegetable Standardization law in California. Experience under a given set of conditions, checked against a few determinations of soluble solids, enables one to pick melons that will ship well and be of good quality.

Changes of Composition in Storage.—Some growers and shippers believe that melons picked and shipped in an immature condition will ripen during transit. To test this point, Chase, *et al.* (1924), placed melons of uniform maturity in cold storage for 10 days. Analyses before storage, upon removal therefrom, and 2 days after removal, showed that there was little change during storage at 3°C. Two days after removal from storage, there was a loss of 1 per cent in sugar content. There was, however, some improvement in flavor, because of the softening of the fruit.

Relation of Maturity to Shipping Quality.—Before the soluble-solids test came into use, McKay, *et al.* (1922), studied shipments of melons, to determine the effect of maturity at time of harvest upon quality after arrival at the market.

TABLE 74.—RELATION OF MATURITY TO QUALITY OF MELONS AFTER SHIPMENT FROM CALIFORNIA TO NEW YORK
(*McKay, Fisher, and Nelson*)

Defects	Condition on unloading			Condition 2 days later		
	Field run, per cent	Picked full slip, per cent	Picked before full slip, per cent	Field run, per cent	Picked full slip, per cent	Picked before full slip, per cent
Too soft	13.4	12.7	9.7	20.7	17.7	11.6
Too yellow	6.1	11.5	2.2	14.9	27.0	10.7
Decayed	0.3	0.1	0.1	5.1	3.1	0.4
Cukie (immature)	....	....	....	13.9	0.1	1.9
Total defects	....	....	....	54.6	47.9	24.6

The condition of the melons 2 days after removal from the refrigerator cars in New York, indicates that the field-run melons, as picked by commercial growers, contained some that were too ripe and many that

were too green when picked. Ripening is almost completely halted by the low temperature of the refrigerator car. A melon picked too immature, furthermore, never attains a higher sugar content, although some softening occurs. The above experiment indicates that full-slip melons were somewhat too soft and too yellow, for the most part, while those picked just before full slip had the least percentage of defects.

Picking.—Melons should be picked early in the forenoon, before the fruit has been warmed by the sun. A canvas sack, slung from the shoulders, with openings at both ends, is used. Such sacks are not likely to be dragged on the ground by the picker and may be emptied conveniently into the field crates for hauling to the packing shed. Hauling from the field in large sacks or loose in a wagon box causes much bruising, which leads to poor market quality and to decay. At the packing shed, the melons should be placed in padded bins, whence they are passed, in grading, to the canvas-bottomed packing table.

Tests by McKay, *et al.* (1922), on shipments from California to New York, showed that, 2 days after unloading at destination, there were 26.9 per cent defective melons in commercially handled lots, compared to 4.2 per cent in handled carefully lots.

Marketing

Grading.—There are no standard grades for melons, but the fruit is graded for uniformity in size and for maturity. Careful shippers discard all cracked, bruised, diseased, ill-shaped, soft, overripe, and immature fruit as well as the "slickers," which are not netted at the apical end. The riper melons are shipped to nearby points. Size of fruit is designated by style of crate and number of fruit contained, as "Standard 45's," and so forth. Uniformity of size is necessary for an attractive, snug pack, which will carry well.

Shipping Packages.—A number of packages are in general use at the present time in the United States. (1) The "standard" crate holds 45 melons in three tiers of 15 each or 36 melons in three tiers of 12 each. The inside dimensions are 22 by 12 by 12 inches. (2) The inside measurements of the "jumbo" crate are 13 by 13 by 22 inches. It contains 36 or 45 melons somewhat larger than standards. (3) The "pony" crate is 11 by 11 by 22 inches inside and contains 45 or 54 melons, which are smaller than standards. (4) The "standard flat" crate is 4½ by 13 by 23 inches in size. In it are packed 12 or 15 melons in a single tier.

Packing.—The packing shed should provide ample shade. It should be arranged so that the melons are unloaded in the field crates on one side of the shed, whence they are emptied by the grader into bins containing different sizes. The grader removes all defective melons. Packers work on the opposite side of the table from the graders.

In packing, the melons are placed end to end in regular rows. They are selected in size, so as just to fill the crate, with a slight bulge on top. The Burrill Gem variety, being oblong in shape, is packed in a slanting position instead of end to end. The flat crate is preferred to the standard one for this variety.

Wrapping.—The use of tissue-paper wraps is general, especially for the pink-meat type of melon. It is claimed that wrapped melons do not soften so rapidly if delayed in loading or after unloading from refrigerator cars. Wrapping reduces damage in shipment from rubbing or jarring and retards evaporation and softening of the fruit. Wrapped melons, however, do not cool off so rapidly as unwrapped fruit does after loading, and after unloading, the paper retains moisture, which promotes molding and decay. Experimental shipments from Imperial Valley to New York showed that wrapped melons contained a higher percentage of defective ones than did those shipped unwrapped.

Factors Affecting Price and Consumption.—There are seven factors affecting price and consumption.

Distribution.—The daily carlot receipts on each market have a great influence on price. Proper distribution from the main shipping sections prevents oversupplying the few large markets while smaller cities are insufficiently supplied.

Condition and Quality of Receipts.—Prices and consumption are depressed by large quantities of green, overripe, or rain-injured fruits being placed on the market.

Source of Supply.—Western ones usually sell on eastern markets at higher prices than do southern or locally grown melons, because of their higher eating quality, more uniform pack, and better keeping quality. Melons grown in humid regions fluctuate in quality, depending on weather conditions.

Volume of Crop.—Acreage, in various sections, fluctuates from year to year, and the volume of shipments varies even more. An oversupplied market lowers prices and causes much good stock to deteriorate before it can be sold, thus further depressing the market.

The Weather.—Cool or rainy weather in the large consuming centers retards consumption, and fair, warm weather stimulates it.

Quality, Price, and Volume of Competing Crops.—Melons, watermelons, grapes, grapefruit, and peaches are used for the same purposes; therefore, an oversupply of one results in decreased demand and lower prices for the others.

Market Preferences as to Size of Fruit, Type of Crate, and Variety.—Generally prices are proportionately higher on flats than on any other type of package. It is more costly, however, to pack and ship in flats than in standards. Pony 54's sell at a lower price than standard 45's. Though the chief demand is for medium-sized melons, the jumbo brings

a higher price than does the standard. Green-fleshed varieties are lower in price than salmon-tint or pink-meat types. The demand for varieties having pink or orange flesh is increasing.

Producing Regions.—California, Colorado, Georgia, Maryland, and Arkansas lead in acreage and in carlot shipments of melons. Acreage and shipments of melons have increased rapidly in recent years. This fact is due to a longer season of consumption than existed formerly, to better quality, better distribution of the crop, and increased popularity among consumers.

Acreage, yield, and price vary widely from year to year. In the East, the yield is much influenced by weather conditions; in the West, it is larger and steadier from year to year. In some cases, low yields are due to unsatisfactory market conditions, resulting in part of the crop's being left in the field unpicked. During the period 1921 to 1923, the number of crates marketed from each acre was 72 to 100 in South Carolina, 80 to 90 in New Jersey, 148 to 180 in California, and 125 to 192 in Colorado.

Shipping Seasons.—The time at which the crop matures, the length of the shipping season, and the volume of shipments from different sections are factors of great importance in marketing. Table 75 gives these data for the leading shipping districts.

TABLE 75.—SHIPPING SEASONS AND CARLOT SHIPMENTS FROM THE MOST IMPORTANT MELON DISTRICTS

District	Shipping season	Carlots shipped				
		1922	1923	1924	1925	1926
Arizona	July	1,566	1,208	1,864	3,057	3,182
Arkansas	July, August	990	337	1,052	1,245	1,078
California						
Imperial Valley	May to July	12,243	12,992	15,758	13,410	11,678
Central district	July to October	2,989	2,451	2,535	3,086	2,211
Colorado	August to October	4,420	2,195	2,654	3,224	4,081
Delaware	July to September	843	818	511	658	551
Georgia	June, July	1,630	216	586	117	108
Indiana	July to September	894	681	822	1,087	595
Maryland	July to September	1,233	1,270	699	1,116	1,285
Michigan	August, September	465	306	114	146	83
New Mexico	July to September	275	364	518	574	640
North Carolina	July, August	700	620	401	655	394
Texas	May to September	186	387	416	469	492
Total for United States		29,930	24,771	28,931	30,165	27,354

The peak shipments from different districts vary so that they do not all compete with each other. The western and the eastern states, however, compete on the larger markets after the middle of June. The

eastern and southern districts have the advantage of being near the markets and have low freight and refrigeration charges. The western districts, on the other hand, pack a high-quality product and have made more progress in standardization. The higher price received for the western melons equalizes the additional cost of transportation.

The earliest melons come, in April, from the west coast of Mexico. The Imperial Valley season begins about May 1, and shipments increase rapidly, until a peak is reached, early in June. Then the Salt River Valley district in Arizona begins to ship heavily, reaching a peak in early July. Following Arizona, and in July, come the Tulare; and, in August, the Turlock districts of California. Partly overlapping the Turlock season, the Rocky Ford district of Colorado commences in August, with heavy shipments in September. Western Nevada, Yakima Valley in Washington, and New Mexico also furnish many cars of late melons. In the South, the earliest melons move from Florida and southern Texas in May, though shipments are small. In June, Georgia ships heavily, is succeeded by South Carolina about July first, and shipments from North Carolina reach a peak the latter part of July. Maryland, Delaware, Arkansas, and Indiana ship heavily early in August. Late in August, Michigan commences shipping and continues to do so until frost.

Varieties

American seed catalogs list over 200 horticultural varieties. As many of these are nearly or quite the same, they may be classified into distinct varietal groups (Rosa, 1926*B*). These groups are named after the leading variety in each group. Only a few varieties are important; many of the older types are being discontinued, and new ones are taking their places.

Jenny Lind.—Fruit small, oblate, ribbed, and well netted, with shallow, smooth sutures. Some fruits have a protruding button at the stylar end. Jenny Lind has green flesh. Fordhook is a similar variety, with pink flesh. Champlain, a pink-fleshed variety, is intermediate in fruit type between Emerald Gem and Jenny Lind. These are all grown for local markets. Their quality is good, but they are not adapted to shipment.

Netted Gem.—Fruit small to medium, oval, ribbed, well netted; sutures shallow, not netted over; flesh green; season of maturity, early. Varieties of this group are no longer important, although the introduction of the Netted Gem, in 1880, and its subsequent improvement were important factors in the development of the melon industry. Netted Gem, Early Imperial, Bottomly, and Early Watters belong to this group. Sugar Sweet, Model, Maryland, and Early Knight are similar varieties,

which have a slight neck at the stem end. The term "Rocky Ford" has been loosely applied to this group as well as to the Pollock, which has been derived from it.

Pollock.—Fruit small to medium, rounded oval, not ribbed, heavily netted; sutures absent or shallow and well netted over; season of maturity, medium early. Green-fleshed varieties of this group are Eden Gem, Green-meated Pollock, Netted Rock, Mission Bell, and Buskirk's Blight-proof. Pink-fleshed varieties are Golden Pollock, Rice's Orange Fleshed, Edward's Perfecto, and Hale's Best. Varieties with pink flesh around the cavity are Salmon Tint, Pollock Ten Twenty-Five, and Gold-lined Pollock.

This group constitutes most of the commercial crop, Salmon Tint being most important. The acreage of the green-fleshed varieties is small, except in the South. The green meats are somewhat earlier but are said to lack quality. The pink-fleshed varieties are of good appearance and eating quality but are not supposed to be well adapted to long shipment; they are popular on the markets and increasing in importance. Hale's Best is larger and earlier than the other varieties.

Hackensack.—Fruit large, oblate, ribbed; heavy, coarse net; medium-deep, smooth sutures; early maturing. Green-fleshed varieties of this group are Extra-early Hackensack, Long Island Beauty, Baltimore Market, and Large Hackensack. Pink varieties are Greely Wonder and Indiana. These are all grown to some extent for home use and local markets in the East and Middle West. The fruit is too large and too soft for shipping, and the flavor is poor, at least in the green-fleshed varieties.

Tip Top.—Fruit medium to large, obovate, ribbed, sparsely netted, sutures smooth and shallow; skin gray. The flesh is firm in texture, of good flavor, and pink for about two thirds of its thickness, being green next to the rind. Other varieties are Irondequoit, Bender's Surprise, and Ohio Sugar, the last, green fleshed. This group is commercially important for local markets in Indiana, Ohio, New York, and Southern California. It does not set as many fruits per vine as the Pollock type sets.

Osage.—Fruit large, oval, ribbed, sparsely netted; skin dark green; sutures smooth, broad, and medium deep. Late in maturing. The flesh is pink and of good flavor but soft. Shipping quality poor. Other varieties are Extra Early Osage, Miller's Cream, and Bowman's Gold Coin. Emerald Gem is a small-fruited, early-maturing variety belonging to this group. Some of the Osage varieties have white seed.

Hoodoo.—Fruit small, slightly elongated, ribbed, heavily netted; sutures shallow and partly netted over. The flesh is pink, and, though the melon is late in maturing, the shipping quality is excellent. Other varieties are Hearts of Gold, Admiral Togo, Defender, Burrell's Solid

Net. This group is important commercially, especially in Michigan, Colorado, and Nevada.

Burrell's Gem.—Fruit medium sized, elongated, ribbed; netting rather sparse; skin dark green, sutures shallow and smooth. The flesh is pink, firm, and of fine quality. Late in maturing. This group includes Burrell's Gem, Ordway Pink Meat, Pink Queen; it is important in Colorado, New Mexico, and Georgia. It brings a high price because of its thick flesh, rich color, and good flavor. The shipping quality is somewhat inferior to Pollock's, the fruit is more difficult to pick at the right stage of maturity, and, under some conditions, cracks at the apical end, and the shape makes it more difficult to pack.

Persian.—Fruit large, round or slightly oblate, not ribbed, no sutures; netting fine and sparse; flesh pink, firm, and sweet. Late maturing. Other varieties are Armenian and Turkish. Persian is grown only in California, where it is popular on local markets, though little is shipped to the East. This variety is likely to increase in commercial importance. The fruit keep well, but the shipping quality is poor, due to the tendency for soft rot to develop from small bruises on the fruit.

Breeding

In melons, quality is largely influenced by the environmental factors—sunlight, humidity, temperature, and soils. Maturity, sugar content, proper methods of handling in shipment, and marketing are also important. Besides these factors, heredity plays an essential part. The high prices paid for improved varieties, the efforts made to produce them, and the care taken to produce pure seed of standard varieties are evidences of this.

Selection.—Due to the frequency of cross-pollination, there is often considerable variation among individual plants within a variety, and distinct types can be isolated by selection. Blinn (1909), in Colorado, developed a number of varieties, selecting fruit from healthy, vigorous plants bearing fruits of the desired characteristics. The fruit from each plant is cut transversely, and that not having thick, firm flesh and small seed cavities is discarded. The progeny of each selected plant is tested separately the next year, and from the most promising lines, further selections are made. This method is more effective if the flowers, from which selected fruits are derived, are protected from chance cross-pollination.

In 1895, J. P. Pollock of Rocky Ford, Colorado, saved seed from Netted Gem plants, in a field where most of the plants were of a large, salmon-fleshed variety. The seeds were, presumably, cross-pollinated by this unknown variety, the female parent being the Netted Gem. For 8 years, Pollock continued selecting for close, heavy netting and thick, firm flesh. The ribs of the original Netted Gem type were eliminated,

and the netting, much intensified. In 1909, Blinn began selection within the Pollock variety. One of his selections was introduced as Pollock No. 25. Both green- and salmon-meated strains of Pollock were isolated. The earlier Pollock strains had been variable in this respect. In 1917, another selection was introduced as Salmon-Tint Pollock 10-25, in which the inner half of the flesh is salmon colored and the part next to the rind is greenish. This has become our most important variety. Other varieties were developed by Blinn, by selection and from crosses in which the Pollock was usually one of the parents.

Inheritance of Certain Characteristics.—Melons were among the first plants to receive attention in genetic studies. Forty years before the idea of alternative inheritance was definitely promulgated by Mendel, Sagaret (1826) suggested it. From a cross between two distinct varieties, he gave the following as the results in the F_1 hybrids:

Flesh color: Yellow, dominant over white.

Seed color: White, dominant over yellow.

Epidermis: Netted, dominant over smooth.

Ribs: Rather pronounced, dominant over slight.

Flavor: Acid, dominant over sweet.

Lumsden (1914) crossed Delices de la table and Sutton's Superlative. The F_1 generation was non-uniform, and probably one or both parents were heterozygous for some characters. Most of the F_1 plants, however, were intermediate between the parents for most of the characteristics under observation. In the F_2 generation, segregation occurred, as follows:

F_1 fruit		F_2 plants	Ratio
Color of skin	Yellow	58 yellow, 21 green	2.76:1
Form of fruit	Round	58 eliptical, 21 round	2.76:1
Size of seed	Large	59 large, 20 small	2.95:1
Size of fruit	Small	57 large, 22 small	2.59:1
Netting	Netted	Variable	
Ribbing	Ribbed	Variable	

Further segregation occurred for some factors in F_3, but certain self-pollinated plants yielded progenies identical with their F_2 parents, indicating that the type was fixed. Lumsden's results as to ribbing, netting, and some other factors indicate the operation of multiple factors.

Blinn reports that resistance to rust disease is dominant in crosses between resistant and susceptible varieties. McClelland (1921) crossed a mildew-resistant variety of Porto Rico with susceptible plants. He reports that F_1 individuals showed no resistance but that in later generations of this cross, resistant varieties were obtained. Mildew resistance

must be recessive. Time of ripening in F_1 was intermediate between the parental varieties.

Crossing with Other Species.—Bailey (1890) secured no fruit in melons pollinated by White Spine or English cucumbers. In 25 reciprocal crosses, he secured one fruit, which was seedless; seedlessness is not uncommon in cucumbers. Pammel (1892) planted several kinds of cucurbits in rows, so that the vines intermingled; he also made many cross-pollinations by hand but found no evidence of interspecific crossing. Werkenthin (1921) found that pollen of various species of *Cucurbitaceae*, placed on the stigmas of other species, germinates, sends its tube down through the style, and may stimulate the ovary, so that fruit of normal appearance, though seedless, results. Jones and Raynor (1915) report that *Bryonia dioica* pollinated by *C. melo* produced some fruit which contained seeds, which were, however, non-viable. Even if interspecific pollination resulted in fruit setting and the formation of viable seeds, there would be no effect on the flesh of the fruit, which is purely maternal in its origin. Some writers have reported instances of this, but the experimental evidence is much against it. Rosa (1926A) found no immediate effect of pollen on the fruit (metaxenia) in varieties which cross readily.

Seed Production

About 600,000 pounds of melon seed is produced in the United States annually. Most of it is produced in the Rocky Ford district of Colorado, with some in California and Iowa. On the average, one standard crate of melons will produce 1 pound of seed. At Rocky Ford, the average yield is 220 pounds of seed per acre.

In seed production, precautions must be taken to avoid crossing with other varieties and to maintain the quality by eliminating plants which bear poor quality or off-type fruit. Whether certain localities are superior to others in the quality and vigor of the seed produced has not been proved. Many growers believe that seed grown at high altitudes or in the North is superior in earliness and vigor.

For seed production, fruit is allowed to remain in the field until ripe, though the seed is viable 10 days before ripening. The fruit is passed through a chopper, and the pulpy mass is run through revolving screens, to separate the seed and juice from rind and pulp. The seed or the pulp containing it is placed in barrels to ferment for 2 to 4 days, then it can be separated by adding water and stirring. Another method is to cut the melons and scoop out the seeds and adhering placenta from fruit which has desirable flesh and other characteristics. Seed from hand-cut fruit commands a higher price. The fermentation process is omitted by some growers, and the seeds are washed out at once. Drying, after

separation from the pulp, is accomplished by spreading the seeds in a thin layer on cloth or wire frames, in sunlight.

Diseases

Bacterial Wilt (*Bacillus tracheiphilus*).—This organism is widely distributed and attacks melons, cucumbers, squashes, and pumpkins, while watermelons are almost immune. Should the stem of a wilted plant be cut, there is a mucilaginous exudate if the plant is affected with bacterial wilt. Affected plants wilt, due to plugging of the vessels of the stem by bacteria. The disease seems to be directly connected with the presence and activity of striped and 12-spotted cucumber beetles. According to Rand and Miss Eulows (1920), striped and 12-spotted cucumber beetles provide the sole means for spreading the disease in the field. It is considered probable that the organism overwinters in the intestines of the beetles, for it does not overwinter in the soil or on the seed. The control of wilt depends largely on that of the cucumber beetles. Removal and destruction of wilted plants and spraying the plants with Bordeaux, to act as a repellant to the beetles and for its specific effect as a bacteriacide, are also recommended.

Powdery Mildew (*Erisiphe cichoracearum*).—Powdery mildew is caused by a fungus parasite, attacking all cultivated cucurbits (Reed, 1907), though not severe on watermelons. The mycelial threads run over the surface of the leaf, the epidermal cells of which are pierced by the branching haustoria. Spores are produced in great numbers and are disseminated by wind, causing rapid spread of the disease. Powdery mildew is most common on cucumbers grown in greenhouses but occasionally causes severe damage to other cucurbits in the field. A gray, powdery growth of the fungus occurs on both sides of the leaf, which eventually turns yellow and dies. The disease progresses most rapidly when the fruit begins to ripen; it is little affected by weather conditions. Humphrey (1891) recommended spraying with ammonical copper carbonate for the control of the disease on cucumbers in the field and using S fumes in the greenhouse. Sulfur is toxic to the foliage of melons; hence, it may not be used as a dust or spray. On some cucurbits which are not sensitive to sulphur, as the bush squash, powdery mildew can be effectively controlled by dusting with sulphur.

Rust (*Macrosporum cucumerium*).—Rust sometimes causes extensive damage to melons in all parts of the country, except on the Pacific coast. Its development is favored by the same conditions as those favoring downy mildew and anthracnose. The Pollock strains developed by Blinn are resistant to rust, but this does not imply resistance to other foliage disease, a fact which is often overlooked. Rust is characterized by tan-colored spots about the size of a pinhead, which appear on the leaves in

midseason, enlarge rapidly, merge, and kill the leaf. The enlarged spots appear as concentric rings of darker color. On ripe fruits left in the field, brownish, sunken spots appear, which, under moist conditions, produce masses of olive-colored spores. The stems and immature fruit are not attacked. Brisley (1923) was able to transfer the disease from cantaloupes to cucumbers, watermelons, and even potato and tomato. He found that the fungus mycelium overwintered in dead plants and resumed growth in the spring. The conidial spores remain viable for several months but do not live over winter. Burning the dead vines at the end of the season and crop rotation are important control measures.

Anthracnose (*Colletotrichum lagenarium*).—This disease is sometimes called "blight," though other diseases may also bear the same common name. Melons, cucumbers, watermelons, and several non-economic cucurbits are susceptible; in squashes, only the fruit is attacked. The lesions are sunken spots of brownish, dead tissue on fruit, stems, and leaves. Anthracnose shows a marked relation to weather conditions in its occurrence; hence, the injury varies greatly from year to year. It spreads rapidly in warm, moist weather but is not serious when dry weather prevails during the fruit-ripening period. In humid regions, anthraconose often causes defoliation and premature death of the plants, thus causing the fruit to be of very poor quality. Gardner (1918) found that the optimum temperature range for spore germination was 22 to 27°C., and Edgerton (1915) reports that 24°C. is the optimum temperature for the growth of the fungus. According to Gardner, humidity also affects sporulation, dissemination of spores, their germination on the plant, and, consequently the rate of spread of infection. The scattering of the spores by raindrops is important in their dissemination from diseased to healthy leaves and to the soil in contact with stems and fruit. Cultural operations and harvesting fruit while the vines are wet with dew also spread the spores. The disease is probably introduced into new localities by infected seed. Even careful washing of seed does not remove the spores, which are held on the seed coat. Gardner (1918) states that the spores will not survive on the seed more than 1 year; hence, the use of 2-year-old seed may be advisable. Also, the method of seed disinfection (see p. 444) given under angular leaf spot of cucumber destroys the spores. By seed treatment, Gardner prevented the disease almost completely in fields where the soil was not infected from the previous year's crop. The fungus is able to survive one winter in the soil, making crop rotation necessary.

Johnson (1911), at Norfolk, Virginia., obtained an increase of nearly 200 per cent from four applications of Bordeaux (3:5:50) in 1908, when anthracnose appeared early, but the increase was only 11.2 per cent in 1910, when the disease appeared later. Jarvis (1912) found that cantaloupes were more resistant than cucumbers to injury by Bordeaux

spray, though both were considerably injured by a strong solution (6:6:50 formula). Weak Bordeaux (3:3:50) caused slight burning but kept the plants alive and productive for 2 to 3 weeks longer than unsprayed plants, in season when both anthracnose and downy mildew were severe. In seasons when diseases were absent, however, the maturing of the crop was somewhat retarded by spraying. Various S sprays were found by Johnson to be extremely toxic to the melon plants. Gardner found that leaves coated on the upper surface with Bordeaux could not be infected by the fungus on that surface but that infection was easily secured by inoculation on the undersides of such leaves. To control foliage diseases by spraying, the undersides of the leaves must be coated with spray material. Jehle and Potts (1924), obtained good control with copper-lime dust (19 parts monohydrated copper sulfate, 81 parts hydrated lime) applied five times during the latter part of the growing season. Increased yields, a 2- to 3-weeks' longer picking season, and better quality of fruit resulted. The 19 per cent monohydrated-copper-sulfate-lime dust is not toxic to plants and controls downy mildew and anthracnose effectively. Little difference was found in cost or effectiveness between dusting and spraying with Bordeaux.

Downy Mildew (*Pseudoperonospora cubenesis*).—Downy mildew attacks melons and cucumbers, affecting the leaves only. It occurs in the East and South and is often associated with anthracnose and rust, as these diseases develop in warm, humid weather. According to Stewart (1897), the fungus attacks the oldest leaves first, progressing toward the tips of the vines. The leaves first show yellow spots, which enlarge and coalesce, until, finally, the entire leaf dies. If the disease starts early in the season, little fruit is produced. Later infections result in defoliation, with reduced yield and poor quality of fruit.

Control is by spraying or dusting, as for anthracnose. Seed disinfection does not prevent mildew. According to Martin (1917), weak Bordeaux (2:4:50) should be used for early sprayings, before the disease has become well established in the field; but after midseason, the 4:4:50 formula should be used. Since infections occur mostly on the underside of leaves, spraying should be especially directed toward that region. Geise, *et al.* (1922), controlled downy mildew with a dust mixture containing 16 per cent anhydrous copper sulphate, but this material injured the leaves and resulted in decreased yield.

Insects

Striped Cucumber Beetle (*Diabrotica vittata*).—The adult is about $\frac{3}{16}$ inch long. Its wing covers are striped yellow and black. It overwinters under dry weeds and trash and emerges from hibernation early in the spring. The cotyledons and stems of young melon plants are

its preferred food. On older plants, the tips of the stems, the fruits, and especially the blossoms are attacked. Other vegetables are attacked when cucurbits are lacking. Much damage is done to the older melon plants by the larvae, which bore into the stem below the surface of the ground, causing the plants to wilt. This insect disseminates bacterial wilt, Fusarium wilt, and mosaic. Infection is carried from plant to plant in the mouth parts of adult beetles. They probably act also as the sole means of overwintering the organism causing bacterial wilt.

The eggs are laid in cracks in the soil near plants. They hatch in 1 to 2 weeks. The larval period of 1 to 6 weeks is passed in the soil or in the tap-roots of the plants. Pupation, which requires 5 to 14 days, takes place in the soil. All stages of development proceed more rapidly at warm temperatures. In the North, there is only one generation per year, but in the South, there are several. Upon the approach of cool weather, the beetles seek shelter for the winter beneath dead plants.

Control measures fall into three groups, as follows:

Natural Parasites.—There are several parasitic and predatory-insect enemies, and birds help to keep the beetles in check.

Preventive Measures.—Covering small plants with protectors of screen wire or cheesecloth, burning old plants and weeds, and use of a trap crop, such as early bush squash, of which the beetles are especially fond, are helpful measures.

Insecticides.—Spraying with arsenate of lead, though often recommended, is not effective when the insects are numerous. Dust applications of arsenicals, however, and nicotine dusts have proved effective on a field scale. Cardinell and Page (1922) found that, in Missouri, 4 per cent nicotine-sulphate dust (equivalent to 10 per cent Blackleaf 40) controlled both lice and striped beetles. They found that beetles alone were controlled with a mixture of 1 pound of lead arsenate, ½ pound of Paris Green, and 15 pounds of hydrated or air-slaked lime. This was applied at the rate of 1 pound to 300 hills at the first application, when plants were showing the first leaf; 1 pound to 200 hills at the second application, when plants had three to five leaves; and 1 pound to 150 hills at the third application, when plants had begun to send out runners. Nicotine dust acts both as a repellant and as a contact insecticide. The protective action, however, may be increased by adding arsenicals to the nicodust.

Dudley, *et al.* (1923), obtained the best results experimentally with a dust consisting of 8 per cent nicotine-sulfate solution, 25 per cent powdered copper sulfate, and 67 per cent hydrated lime. They found that mixtures containing copper sulfate were much more effective against the insects than mixtures of lime and nicotine sulfate alone.

Houser and Balduf (1925) found that growth was much retarded in cucumber plants dusted with mixtures containing hydrated lime. No

such injurious effects resulted from mixtures containing gypsum, however. These investigators found that the most satisfactory control for beetles was to apply once a week a dust containing 1 part calcium arsenate: 20 parts of gypsum.

Twelve-spotted Cucumber Beetles (*Diabrotica 12-punctata*).—This insect is not so widely distributed as is the striped beetle. Larvae are often referred to as "corn rootworms." Control measures for this species on cucurbits are the same as for the striped beetle.

Melon Aphis (*Aphis gossypii*).—The melon, or cotton, louse is a small, green, soft-bodied insect, most injurious to melons as well as to cucumbers, watermelons, and other crops. It occurs in all parts of the United States. Its attack commences on a few plants scattered through the field, and these should be destroyed before there is a general infestation. The insects gather on the undersides of the leaves and cause them to curl downward, so that it is difficult to reach the aphis with spraying materials. The plants are weakened, and a heavy attack causes them to become brown and dry. The insects increase rapidly; Paddock (1919) states that, in Texas, 51 generations completed their life cycle in a year. Reproduction is asexual, by viviparous females, as long as conditions are favorable; but sexual forms usually appear in the autumn.

Control is relatively easy, if treatment is begun before the leaves begin curling. A solution of 1 part 40 per cent nicotine sulfate solution: 1,000 parts of water or a nicotine dust is effective. Cardinell and Page (1922) found a dust containing 2 per cent nicotine sulfate to be more practical for field use against aphis than was a liquid spray. Efforts have been made to control aphis by importing large numbers of lady beetles. Its rapid reproduction, however, under favorable conditions renders control by this method ineffective.

Pickle and Melon Worms (*Diaphania*).—These insects were reported by Smith (1911) to be the most injurious of all on melons in the South. The adult is a large moth, emerging in late spring. Eggs are laid on all parts of cucurbitous plants. By boring into the fruit before or during the ripening season, the larvae cause the punctured fruit to become sour. The principal preventive measures for these insects are early planting and the use of bush squash planted at intervals through the field as a trap crop. Pickle-worm larvae are found mostly in the blossoms of squash, while melon worms feed on the foliage and mature fruit. The squash plants, with their attendant insects population, should be destroyed with kerosene toward the end of the season.

Root Knot.—The garden nematode (*Heteroda radicola*) is the cause. It is a worm of microscopic size, which bores into the roots, causing hypertrophied growth, or galls. Since the nametode attacks many species of plants, including vegetables, weeds, fruit trees, and farm crops, it is difficult to control. It thrives in muck and sandy or sandy-loam soils

but is seldom destructive in heavy soils or in cold regions. No satisfactory control is known. It is claimed that if, for 1 year, no host plants are allowed to grow on the land the infection will be greatly reduced and if immune crops are grown for several years the soil will be rid of nematodes. There is always danger of re-infecting the soil from adjacent infected areas through manures, irrigation water, infested plants, seed potatoes, or nursery stock. Crops immune to the garden nematode are as follows: cereals and nearly all kinds of grasses; chufus and peanuts; cowpea (Brabham, Iron, and Victor varieties); red top; sorghum, soy bean (Laredo variety,) and velvet bean. Highly resistant crops are sweet potato, asparagus, and onion.

SECTION B. WINTER MELONS

Winter melons belong to the sub-species *Cucumis melo* var. *inodorus*. The principal types grown in America are the Casabas and the Honey Dew melons. They are firm fleshed and good keepers; hence, are called "winter melons."

Casabas.—The plants are larger and coarser and the leaves are more deeply lobed than are those of cantaloupes. The ovaries are five-loculed. There are five stamens both in the hermaphroditic and in the staminate flowers. The fruit is very firm, with thick, white flesh and a small cavity, which is almost completely filled by the placenta and the seeds. The outer layer of the fruit wall consists of a single layer of palisade-like cells the outer half of which is greatly thickened. It is this layer that gives the fruit its hard shell, for there is no layer of stone cells, as in pumpkins. The fruits are not netted or warty but are either smooth or have numerous, small, longitudinal grooves, converging at the stem end. The peduncle does not abscise upon ripening, and the main indication of maturity is the development of a deep-yellow color in the skin and softening of the fruit at the stylar end. The flesh of the fruit lacks the musky odor of cantaloupes and has a different flavor. Fruit is rather large, averaging 3 to 5 pounds in weight, and varies in shape, according to the variety.

Youngkin (1920) states that casabas were first grown in America, in 1878, from seed imported by Dr. J. D. B. Stillman, at Chico, California. It is said to have come from Asia Minor, and the name is derived from the town of Kassaba, near Smyrna. Commercial production has increased in recent years. Casabas seem to be adapted to culture in the Southwest only. A long growing season, high temperatures, and low atmospheric humidity are required for the best development. Furthermore, the plants are especially susceptible to anthracnose and other fungus diseases, when grown in a humid climate.

The principal shipping district is at Turlock, California, whence many carloads are shipped to eastern markets, from August until

November. The fruit is usually packed in crates lined with straw. To nearby points it may be shipped in bulk. It is generally harvested rather immature but softens somewhat in shipment. The best edible condition is not attained unless the fruit remains on the plant until fully mature. It may be gathered in autumn and placed in a cool, dry room, where it will keep for 3 months or longer. The sugar content is not so high as it is in cantaloupes, but when fully ripened, the flavor is good.

There are several varieties of casabas, Golden Beauty and Santa Claus being the most important commercially. Winter Pineapple and Maltese are others.

Honey Dew.—This melon belongs to the same group as the casabas, but the plant and fruit characteristics are more nearly like those of cantaloupes. Honey Dew is an American name for the French variety, White Antibes, which has long been grown in Algeria and southern France for shipment (without refrigeration) to northern European countries. Bailey (1895) first tested this variety in America. It was re-introduced in 1912 and became extensively cultivated in Colorado. The Honey Dew is now grown commercially in the Southwest and, to a limited extent, in other parts of the country. The fruit has an ivory white, smooth skin and thick, greenish flesh. There is also a pink-fleshed strain. The fruit is large, ranging from 3 to 5 pounds. The stem does not slip at maturity. Softening of the blossom end of the fruit and change of color from white to cream are the main indications of maturity.

The shipping season for Honey Dew begins somewhat earlier than for Casaba and continues until November. The melons are usually shipped in flats, containing 9 to 15 melons. Fruit is often picked for shipment too immature, and the demand has been limited by the poor flavor of such fruit. The sugar content when the fruit is fully ripe is much higher than in Casabas and somewhat higher than in cantaloupes.

The general culture of Casaba and Honey Dew melons is similar to that of cantaloupes.

SECTION C. CUCUMBER

The cucumber is the most widely grown species of the family *Cucurbitaceae*, though its commercial production is not so important as that of melons. Cucumber culture is of three types: (1) pickle production, (2) field production of slicing cucumbers, (3) greenhouse culture.

Taxonomy.—Cucumber, *Cucumis sativus* L., belongs to the same genus as does melon. The cucumber of Sikkim, a large-fruited form, eaten either raw or cooked, is by Naudin (1859) placed in the same species as the ordinary cucumber. The West India gherkin, introduced to the United States from Jamaica in 1793, is by some authors placed in another species, *C. anguria;* by others, in a separate genus, *Anguria sativus.*

The American wild cucumber belongs to the genus *Micrampelis*, and is of no direct economic importance.

History.—Cucumbers are native to the East Indies, though the wild progenitor of the species is unknown. They are mentioned in the Old Testament as a food in ancient Egypt. They have been cultivated in the Orient for 3,000 or 4,000 years and were known to the Greeks and Romans, through whom they were introduced to Europe. Cucumbers have been grown in America since the earliest settlements.

Plant Characteristics

The plant resembles that of the melons in structure and mode of development. The leaves being more sharply angled are distinguishable from those of melons.

Flowers.—The Lemon variety bears hermaphroditic flowers, but most varieties are monoecious. The pistillate flowers occur singly in

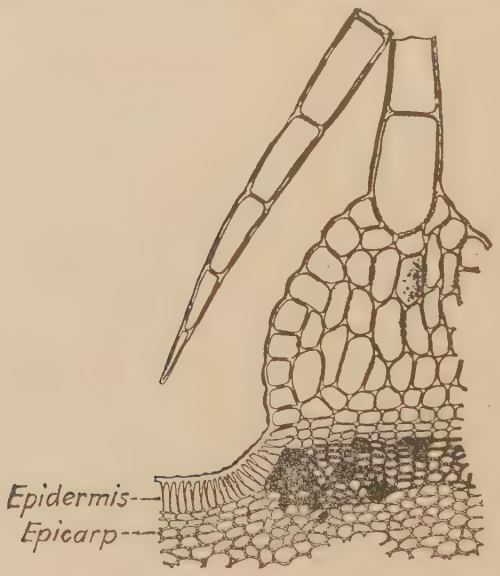

Fig. 81.—Section through a wart on a cucumber fruit, surmounted by a trichome. (*After Miss Barber.*)

the axils of secondary branches, which arise from primary branches and from the central stem. Some varieties are characterized by having two pistillate flowers per node. The staminate flowers appear in other leaf axils in clusters of five. Pollination is performed chiefly by honeybees.

Fruit.—The fruit varies in size in different varieties. It is generally elongated or oval. It is rounded triangular in cross-section, due to the greater development of the pericarp at the base of the three seed-bearing placentae. Seedless fruits or portions of fruits are cylindrical. The rind

is green in immature fruits, due to chlorophyll in the sub-epidermal cells; upon maturity, it becomes yellowish white in some varieties and brown in others. The epidermal layer bears many proliferated areas, forming warty protuberances, capped by a trichome, or spine, which is detached during growth. The structure of the pericarp is similar to that of cantaloupes. The three locules are completely filled with the parietal placentae and the seed.

Seed.—The numerous white seeds are borne in longitudinal rows. They are similar in size and shape to those of melons. In the edible stage of the fruit, the seeds are rather inconspicuous, being only partially developed. When the seed coats begin to harden, the fruit is no longer palatable.

Fruiting Habits.—Fruits are borne on the first node of each fruiting branch. Production continues for 2 or 3 months, if the immature fruits are picked regularly. Golinska (1925) showed that fruit production during a long growing season tends to occur in cycles of alternating low and high production; some varieties have three such cycles during a period of over 2 months, while others have five. She found a low, positive correlation between number of fruits at each picking and weight of individual fruits. She found also that the number of days required for the fruit to attain marketable size varies from 9 to 34 days, according to its location on the plant. The development of those located on the distal portions of a branch is inhibited by more basally situated fruit. This fact justifies the greenhouse growers' practice of pruning the branches, so that only one or two fruits set on each branch.

Parthenocarpy.—Some varieties, notably the English greenhouse cucumbers, set fruit without pollination. This is a case of vegetative parthenocarpy. The tissues of the fruit, except the seeds, develop without the stimulus of fertilization. Seed-bearing fruits are obtained, if pollination is provided; they are somewhat different in shape from seedless fruits. When grown in greenhouses, bees are provided for pollination, though American varieties occasionally set fruit parthenocarpically.

Climatic and Soil Requirements

The plants are killed by frost. They cannot be hardened to withstand freezing. Warm temperatures, 25 to 30°C. are most favorable for growth, but heat is not so essential as for melons. It is therefore possible to grow cucumbers successfully in regions too cool for melons. The short season required—60 to 70 days—for production of fruit of edible size makes possible the outdoor culture of cucumbers in northern sections.

Kotowski (1926) studied the germination of cucumber seed planted in sand, at constant temperatures. Table 76 gives his results.

TABLE 76.—EFFECT OF SOIL TEMPERATURE ON GERMINATION OF CUCUMBER SEED (*Kotowski*, 1926)

	Temperature			
	11°C.	18°C.	25°C.	30°C.
First seedling, days after sowing	..	6	4	3
Last seedling, days after sowing	..	10	6	4
Per cent of seeds germinated	0	68	89	91
Velocity of germination	..	10.0	23.8	33.3

The lower limit for germination is between 11 and 18°C. The percentage as well as the speed of germination increases at higher temperatures.

Cucumbers grow well on any fertile soil. Where the crop is intended for early market, light, sandy soils are preferred. Pickling cucumbers are usually grown on heavier soil types, for in this case, earliness is not important. Moisture and plant-food supply, conducive to large total yield, are more generally met with on the heavier soils. Very heavy yields of pickling cucumbers are secured on peat soils in California.

CULTURE

Planting.—Where extreme earliness of maturity is desired, the same methods of transplanting or of forcing with plant protectors are used as for melons. Cucumbers are more easily transplanted than melons.

In planting, an excess of seed should be sown and the weaker and smaller plants, removed early in the season. Gregory (1917) shows that the size of a plant at the end of a period of 30 days is directly proportional to the area of the cotyledons in the seedling. He found also a positive correlation between growth rate of main stem and laterals and weight of fruit produced in the first two "flushes" (fruiting cycles). Hence, the desirability of selecting the larger seedlings, which show the effect of a good early start throughout the later development of the plant.

The same general methods of planting, either in hills or in drills, are followed as for melons, except that the space between the plants is less.

Field Production of Slicing Cucumbers.—This is carried on in all parts of the country, especially in the South, where climatic conditions make possible the production of an early-spring crop for northern markets.

Methods for field production of cucumbers are almost identical to those of melons.

Field Production of Cucumbers for Pickles.—In 1922, there were 52,400 acres planted for pickles in the United States, and the production

was 2,619,480 bushels—a crop somewhat below normal. Michigan is the leading state in production of pickles, growing one third of the total for the entire country. Pickles are also extensively grown in New York, New Jersey, Iowa, and California. Cool regions are preferred for pickle growing, as the harvest season is longer and the quality is said to be best, when the crop matures during rather cool weather.

Pickles are usually grown under contract by farmers, who deliver the crop as harvested to the pickle factory or to a salting station. Price varies according to size, the smallest grade, 1½ to 2½ inches in length being the most valuable; while the largest size, 4 to 5 inches in length, is cheap. The cheapest methods of production consistent with fair yields are generally practiced. The principal expense is the harvesting. Fields must be gone over every day or two, to secure the rapidly developing fruits before they become oversized. Yields vary from 3 to 10 tons per acre, depending upon cultural conditions and the size at which the fruits are picked. Pickles manufactured from the smallest fruit are known commercially as "gherkins." The largest fruits are usually used for Dill pickles.

Cucumber Production under Glass.—In cucumber forcing, the crop is grown to maturity under glass. Both greenhouses and cold frames are used extensively. Greenhouse culture is highly developed in the vicinity of the larger northern cities. Fall, winter, and spring crops are grown in rotation with other vegetables or with flowers.

In the Norfolk district of Virginia and in other southern localities, cucumbers are grown in early spring, with a slight amount of protection. Cheap, movable types of cold frames are used. The plants are started in a hotbed or small greenhouse and are transplanted to the frames, which may be removed when harvesting commences. In this way, cucumbers may be secured several weeks earlier than the field crop in the same locality.

On the Pacific coast, near Los Angeles, cucumbers are grown in the winter under cheesecloth-covered frames, which furnish protection on cool nights. Control of fungus diseases by frequent spraying with Bordeaux is especially necessary, when plants are grown under cover.

Harvesting and Marketing

Harvesting.—The picking season extends over a period of 1 to 3 months. During this period, the fruits should be gathered regularly as they reach marketable size, at intervals of 2 or 3 days. Growth of the plant and development of later fruit are inhibited if the early fruits are allowed to become ripe. Therefore, the imperfect fruits, or culls, should also be picked. In harvesting, the stem is cut close to the fruit. The proper size for harvesting slicing cucumbers varies somewhat with the variety. White Spine and other extra-early varieties are 7 to 8 inches

long when at the best edible stage. Long Green, Klondyke, and similar varieties should be 9 or 10 inches long. Pickling cucumbers should be picked so as to produce as large a proportion as possible of the No. 1 grade, which includes fruit from 1½ to 2½ inches in length.

Grading.—The grades of the U. S. Department of Agriculture for slicing cucumbers are as follows:

U. S. Grade No. 1 Fancy shall consist of cucumbers which are fresh, firm, well shaped, have a green color over two-thirds or more of the surface, and are free from damage caused by freezing, mosaic or other diseases, insects, mechanical or other means. A tolerance of 10 per cent by count is allowed.

U. S. Grade No. 1 shall consist of cucumbers which are slightly misshapen but otherwise like U. S. Fancy Grade No. 1. The same tolerance is allowed.

U. S. Grade No. 2 shall consist of cumcumbers which do not meet the requirements of the above grades.

In addition to these grades, any lot may be classified according to size, if 90 per cent, by count, fall within the following length requirements: Small, under 6 inches; medium, 6 to 9 inches; large, over 9 inches.

Packing.—A great variety of market containers is used for cucumbers. Barrels and hampers are generally employed in the Atlantic coastal states. Greenhouse cucumbers and, occasionally, the fancy, field-grown product are packed in regular layers in boxes containing 2 dozen fruits. Paraffined or oiled-paper liners for the shipping package aid in preventing excessive wilting of the fruit in transit. Lug boxes are used in California. Cucumbers are sometimes shipped in bulk.

Producing Regions and Shipping Seasons.—The areas of commercial production are widely distributed and are not so highly specialized as in the case of melons. Florida and southern Texas ship heavily during early spring. From February to July, there is a movement of cucumbers from a succession of shipping districts in the South. During the summer and fall, production for local markets is widely distributed over the whole country. Table 77 shows the shipping seasons and carlot movements from the important cucumber-growing states. Cucumbers are shipped extensively in mixed cars with other vegetables, also.

Cucumbers are not a seasonal fruit, like melons. They are on the markets the year round, from the South in spring, from local supplies in the North in summer, and from the greenhouse in winter.

Varieties

Naudin (1859) described four groups of cultivated varieties—the small, egg-shaped, yellow cucumbers of Russia; the ordinary long green; the short, thick, white cucumbers grown in France; and the large, squashlike ones of Sikkim. Varieties grown in America are of three types, adapted to different kinds of culture:

TABLE 77.—SHIPPING SEASONS AND CARLOT MOVEMENTS OF LEADING CUCUMBER-PRODUCING STATES

State	Shipping season	1922	1923	1924	1925	1926
Alabama	May to July	702	367	576	706	684
California	June to November	68	125	23	125	86
Delaware	July to August	191	225	240	302	304
Florida	March to June	2,034	1,635	1,389	1,963	1,982
Illinois[1]	March to July	68	15	77	245	151
Maryland	July to August	368	446	311	598	487
New Jersey	July to September	164	258	276	481	259
New York	August to October	395	383	694	686	444
North Carolina	June to August	687	1,169	1,639	1,562	869
Ohio[1]	April to August	124	68	111	91	187
South Carolina	May to July	887	720	918	794	668
Texas	April to July	119	42	147	72	316
Virginia	May to August	221	84	387	448	202
Total		6,349	5,692	7,182	8,492	7,180

[1] Partly greenhouse-grown crop from Illinois and Ohio.

English Type.—This is characterized by cylindrical fruit free from spines and often more than 2 feet in length. It grows well with a minimum of light and sets parthenocarpic fruits freely. It is used for both greenhouse and cold-frame culture. The plants do not thrive outdoors. The true English type is little grown in the United States, since the long, seedless fruit is not popular on our markets. It has been used considerably in crosses with the American field type, to produce varieties for greenhouse culture, which combine the free setting habit of the former with the more marketable size, shape, and color of the latter.

Varieties of the English type are Telegraph, Lockie's Perfection, and Rockford Market. Of the intermediate type, from hybrids with field varieties, Rawson's Hothouse; Davis Perfect, originated by Eugene Davis, of Grand Rapids, Michigan; Deltus, introduced in 1920 by Hart and Vick of Rochester, New York; and Hescrow. This last variety, introduced in 1922 by the Horticultural Experiment Station at Vineland, Ontario, was derived from a cross between Sutton's Everyday and Fiske's White Spine. It sets fruit without pollination and has the size and shape demanded by our markets. It is said to produce about 35 fruits per plant, without pollination; but if pollination, with resultant seed formation, takes place, the number of fruits is only half as large.

American Slicing Cucumbers.—This has rather short, thick fruit, roughly triangular in cross-section. The fruits are covered, when young, with spines, which may be either white or black. The plants are rather small, vigorous, and early in season of maturity. The White Spine variety is most important. This is a very old variety of which an

improved strain, Evergreen White Spine, was introduced by Johnson and Stokes in 1886. In the hands of various growers, slightly different strains have been developed. This variety is noted for its earliness and hardiness. Its main defect is lack of green, which causes pale streaks on the distal end of the fruit. The cucumber turns yellowish after picking, giving an appearance of overmaturity. The short, blocky fruits are, moreover, not of the best market type. The ripe fruit of all varities having white spines, is whitish.

Other varieties are Long Green and Klondyke, which have medium-long, slender fruits, with the entire surface dark green in color. They are late in maturing. Kirby's Stay Green is an early, short-fruited type, with very dark-green color. The ripe fruits of these varieties, which have black spines, are yellow to brown in color.

Pickling Type.—This is peculiar for its large number of spines, the small size of its fruits, and its prolific fruiting habit. While cucumbers for pickles are usually harvested when from 1½ to 5 inches long, the fruits of this type may reach 6 or 7 inches in length, if allowed to grow to full maturity. Varieties of Type 2 are sometimes used for pickle production.

Chicago Pickling is the variety almost universally grown for pickles in the United States. Its fruits bear black spines and when ripe, are russet in color, with a trace of netting. Snow's Perfection is a rather similar variety. Boston Pickling (Green Prolific) is used when very small pickles are wanted. Starr (1926) reports that in a large number of selections from these varieties tested in Michigan, the fruit of the Snow was most satisfactory from the pickle manufacturer's point of view; Boston ranked second, but the fruit of the smaller sizes was too slender; the Chicago ranked third.

Breeding

Wellington (1916), by inbreeding, isolated lines from several varieties. He found that some varieties were much more variable than others. Because of the prevalence of cross-pollination, most commercial varieties are more or less heterozygous. At least three generations of inbreeding are required to isolate pure lines. Desirable lines may then be crossed to restore the vegetative vigor, if necessary. For inbreeding, the pistillate flowers are bagged before they open; they are pollinated later by the staminate flowers of the same plant.

Strong (1921) crossed varieties of the English and American types. He found the presence of spines to be dominant to spinelessness and black spines to be dominant over white. The tendency toward parthenocarpy was inherited generally in connection with the black-spine character, suggesting linkage. He obtained, however, a free-setting, white-spine segregate, which bred true for both characters.

Hayes and Jones (1916) found, in the first generation of crosses between certain varieties, a decided stimulus to growth and yield, associated with heterosis, or hybrid vigor. In length and size, the F_1 fruit was intermediate between the parents. In weight of fruit per plant (total yield), the cross Early White Russian × White Spine equaled the most productive parent. White Spine × Long Green gave a 24 per cent increase over the best parent, and Fordhook Famous × Long Green gave an increase of 39 per cent. The conclusion reached was that "first generation crosses may be expected to exceed the higher yielding parent in yield, except when the parents are very similar to each other." Herman (1922) states that a line self-fertilized for three generations declined in vigor and productivity but was restored to full vigor by crossing with another line.

Seed Production

About 1,000,000 pounds of cucumber seed is used in the United States each year. Most of it is produced in Colorado, Michigan, and California. With the majority of American field varieties, 40 fruits produce 1 pound of dry seed. The yield of seed is usually about 250 pounds per acre.

For seed production, the fruits are left on the plant until quite mature. Usually, the whole crop is gathered at one picking, late in the season. They are passed through a pulping machine, or thresher, and, subsequently, the seeds are handled in the same way as melon seed.

Diseases

Bacterial Wilt (*B. tracheiphielus*).—The same organism attacks melons, and the nature of the disease is the same. According to Rand and Miss Eulows (1920), different strains of this bacillus exist, nearly all of which are highly virulent on cucumbers but vary in virulence on other species. Doolittle (1922) reports that American varieties of pickling cucumbers are much more resistant to bacterial wilt than are those from Europe. Only 30 per cent of the plants in the former group wilted, as compared to 90 per cent of the latter, under the same conditions. No immune variety has been found, however.

Angular Leaf Spot (*Bacterium lachrymans*).—Angular leaf spot is a bacterial disease of broad distribution. It attacks cucumber, gherkins, and some of the gourds (*Lagenaria sp.*) but does not attack other economic cucurbits. The lesions on the leaves are irregular spots, bounded by the leaf-veins. At first, these spots are yellowish, then brown, with a white crust of the dried bacterial exudate in the center. Later, these dead areas fall out, giving the leaves a shot-hole appearance. On the stems, scab lesions and droplets of bacterial exudate appear. Circular white

spots appear on the fruit. According to Burger (1914), this organism causes a soft rot of cucumber fruits during shipment, which is a source of considerable loss to southern shippers. Smith and Bryan (1915) state, however, that the leaf-spot organism is not able to cause soft rotting of the fruit, though its lesions may serve as the point of entry for other bacteria which do cause rapid decay. Carsner (1918) finds that infection of leaves and fruit is entirely through the open stomata, by bacteria swimming in a film of water on the surface. Infection, accordingly, occurs chiefly during the day and when moisture is abundant. Carsner states that the spattering effect of the raindrops is important in dissemination of bacteria. Picking or cultivating while the plants are wet also spreads the organism from plant to plant.

The causal organism is sensitive to freezing and does not overwinter in the soil or in the dead plants, at least in the North. Carsner proved that the bacteria do overwinter on the seed, however, which become infected from diseased fruits during seed extraction. The disease is spread by means of the infected seed. The most important control measure is seed disinfection. Gardner and Gilbert (1918) found that 4 per cent formalin was injurious to cucumber seed. Disinfection without injury was secured by soaking for 5 minutes in a 0.1 per cent solution of mercuric chloride. For disinfection, the seeds are placed in cheesecloth bags and stirred constantly while soaking. Upon removal, they are washed at once in running water and placed on trays to dry.

Carsner found no varietal resistance to angular leaf spot, and control measures practiced for other diseases were of little use in checking this malady.

Anthracnose and Downy Mildew.—The nature and control of these diseases are the same as described for melons. Experiments on the control for cucumbers were conducted by Jarvis (1912) over a 9-year period. In seven out of nine seasons, an increase in yield varying from 30 to over 100 per cent was obtained by spraying three or four times with 4:4:50 Bordeaux. This full-strength Bordeaux caused some injury to the foliage of cucumbers, and in the 2 years in which fungus diseases did not occur, the yield was reduced somewhat by spraying. Spraying with Bordeaux caused some retardation in the development of the fruit, also, so that early pickings were always less on sprayed plants, though the increase in later pickings more than made up the loss. Jarvis found that 2:2:50 Bordeaux was effective in controlling diseases and less injurious to foliage. Johnson (1911) found that leaf injury and retardation in maturing of fruit were eliminated by using an excess of lime in the Bordeaux.

Mosaic.—Mosaic disease attacks many cucurbits, but its destructive effects are most marked on cucumbers. The infectuous nature of mosaic is well known. The causal agencies are assumed to be a filterable virus

or an ultramicroscopic organism. Mosaic is most destructive to cucumbers grown in greenhouses and to the pickling crop in the North. The leaves and fruits of affected plants are mottled, with patches of dark and pale green, followed by general yellowing. The fruit becomes warty and misshapen. The leaves become somewhat crumpled and eventually wither or develop irregular brown spots. When infection occurs, young leaves are the first to show the mottled condition. This sign is followed by infection of the whole plant, the advanced stages of disease developing later. Plants infected early produce little or no crop, while those infected late bear some misshapen fruit. Fruit from mosaic-infected vines is worthless for pickles, as it does not absorb the salt brine used in pickling.

Mosaic is easily transferred from diseased to healthy cucumber plants and is transmissible to and from all other cultivated cucurbits, except the genus *Citrullus*, and to many wild members of the *Cucurbitaceae* and other families. Transmission from plant to plant may occur through the thinning, cultivating, and picking operations; and in the greenhouse crop, pruning serves to inoculate healthy plants from those diseased. Insects, however, are usually the most important agents of transmission, especially the aphis and cucumber beetles. Mosaic does not overwinter in the soil or in the insects, nor is it transmitted through the seed of cucumbers and melons. Doolittle and Gilbert (1919), however, find that it is seed-transmitted in the wild cucumber (*Micrampelis lobata*), an annual plant occurring as a weed in northern and eastern states. Doolittle and Walker (1925) state that the perennial roots of milkweed, pokeweed, and catnip may also serve as overwintering hosts. From them, the virus is taken to the cultivated cucurbits by aphis and cucumber beetles. The mosaic of cucurbits may be transferred also to Martynia, pigweed, and pepper, and from pepper to tobacco, and vice versa.

The control of virus diseases is difficult. Soil or seed treatments and spraying do not reach the seat of the trouble. Control of the insects which act as the principle carriers, eradication of the wild host plants in the vicinity, and removal of diseased cucumber plants are most important.

Insects

The principal insect pests are aphis and the striped and spotted cucumber beetles. The nature of their attack and their control were discussed in the section on melons.

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CHAPTER XXII

CUCURBITA

The genus *Cucurbita* contains ten species, three of which, *C. pepo*, *C. maxima* and *C. moschata*, are cultivated annuals and seven are non-cultivated, some annuals, and some perennials. According to Cogniеux (1881), one species is native to China, three are native to India, two to eastern United States, two to California, and two to Mexico. Werkenthin (1922) gives the following key:

I. *C. pepo*. Leaves hairy, 5-lobed, often with white, triangular spots at angles of veins. Peduncles of fruit 5 to 8-ridged, deeply furrowed. The following are groups within *C. pepo*, according to fruit type:

a. Field pumpkin.

b. Vegetable marrow.

c. Crookneck summer squash. (*C. pepo* var. *verrucosa* Naud.)

d. Scallops, cymlings, or bush squash. (*C. pepo* var. *melopepo* L. and *C. pepo* var *condesa*. Bailey.)

e. Nest-egg gourds, (*C. pepo* var. *ovifera* Naud.).

f. Orange gourds (*C. pepo* var. *orangina* Ser. and *C. aurantica*).

II. *C. moschata*. Leaves more rounded than in *C. pepo* but lobed. Calyx tube not campanulate. Peduncles five-ridged and enlarged next to fruit (includes *C. melosperma* Al. Braun.). Varieties of this species are called "pumpkins," "cushaws," and "winter squash."

III. *C. maxima*. Leaves orbicular or kidney shaped. Commonly not lobed or with fine, short, rounded lobes. Calyx tube of staminate flowers campanulate. Peduncle of fruit cylindrical or claviform, never ridged. Varieties of this species are horticulturally considered as winter squash.

Russell (1924) discovered apparently constant specific characters in the mature seed of cultivated *Cucurbitae*, and he devised the following key, placing varieties on the basis of these characters:

I. Scar (micropyle and hilum) obliquely truncate. Face of seed pure white or clear brown. *C. maxima*.

II. Scar squarely truncate or rounded. Face of seed ashy grey or whitish.

a. Margin same color as face of seed; usually smooth, not swollen. *C. pepo*.

b. Margin darker than face of seed, rarely smooth, often swollen and corky or roughened or striated, *C. moschata*.

Naudin's original classification was on the basis of interfertility. Lotsey (1919) confirmed Naudin's conclusion that it was impossible to cross *C. pepo* or *C. maxima* with *C. moschata* or with each other. He secured fertile crosses between *C. pepo* and *C. aurantica*, but the latter is considered by Naudin to be merely a distinct variety of *C. pepo*. Drude (1918)

FIG. 82.—Seeds of representative varieties of 3 species of Cururbitae. A, B. *Cucurbita maxima*. C, D. *Cucurbita pepo*. E, F. *Cucurbita moschata*. (*After Russell.*)

found that, in general, the different species do not cross, though he secured one fertile hybrid between *C. pepo* and *C. ficicola*. Bailey (1890) states that *C. pepo* and *C. maxima* do not cross and that neither do *C. maxima* and *C. moschata* but that *C. pepo* and *C. moschata* could be crossed. Kaslov (1925) found that this last cross was most difficult and gave sterile F_1 plants. Castetter and Erwin (1927) find, however, that the *maxima* × *moschata* cross is possible, while *pepo* × *maxima* gave sterile progeny. Some confusion concerning species crosses has arisen, because the terms "pumpkin" and "squash," as popularly used, do not always agree with taxonomic species.

History.—Apparently, the term "squash," derived from the Indians of New England, was originally applied only to *Cucurbitae* used in the immature condition as summer vegetables, whereas now it is generally used for all edible varieties. Vegetable marrow is the English equivalent for squash; and in Europe, squash are termed "gourds," though true gourds are mostly non-edible and belong to the genus *Laginaria*. The winter Crookneck, or cushaw (*C. moschata*), is said to have been grown in New England from very early times and is referred to by Herriot, in 1586, as the "Ecushaw." The term "pumpkin" is used for some of the larger and coarser sorts of *C. pepo* and *C. moschata*, with long trailing stems, and, grown chiefly for stock feed. "Pumpkin" is derived from the Greek *pepon* and referred originally to any ripe fruit; later, to any large fruit

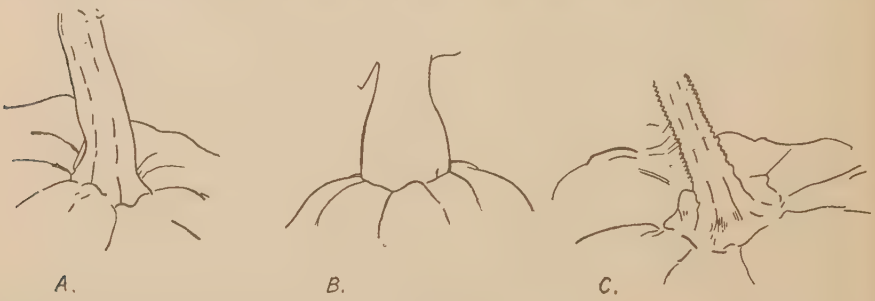

Fig. 83.—Peduncles characteristic of 3 species of Cucurbitae. A. *Cucurbita pepo*. B. *Cucurbita maxima*. C. *Cucurbita moschata*. (*After Bailey*).

(Sturtevant, 1891). Large-fruited cucurbits, spoken of as "pompions" and "citruls," were known in Europe before the discovery of America, but American pumpkins are probably native to New England.

Carrier (1924) says

> The Indians grew a number of plants with creeping vines which the white explorers had never seen before, and to which they gave the name of the European plants which they nearest resembled . . . It seems quite clear that all the squashes and ordinary field pumpkins grown now in America, were common food crops of the Indians.

Herriot, in 1590, described summer squash grown by the Indians in Virginia, and Smith, in 1616, lists "pumpions and gourds" among the Indian crops of New England. All varieties of *C. maxima*, however, are considered to be native to the Old World, while *C. pepo* and *C. moschata* are native to north America.

Plant Characteristics

Stems.—Three to eight lateral branches arise from as many nodes near the base of the main axis. The stems are trailing and, in most varieties,

grow to a length of several feet. Two groups of varieties in *C. pepo*—scallops and vegetable marrows—have short, semi-erect stems, however. These are known as "bush" squash. This form differs from the common, trailing plant type, in that the internodes are much shortened and the tendrils absent. The morphology of the stem of *Cucurbitae* has been described by Holroyd (1924). According to Yasuda (1903), the vascular bundles are bicollateral, and sieve tubes occur not only in the phloem but also in tissue outside of it. These are very large, being one of the distinctive characteristics of the genus. The xylem vessels are also well developed, as the tissue becomes older, being easily perceptible to the eye (0.25 to 0.5 millimeter in diameter). He finds also that the stems store starch, this being deposited mainly in the medullary rays.

Leaves.—The leaves are simple, three- to five-lobed, the depth of the lobes varying between species and varieties. In *C. pepo*, the leaves are of harsh texture, while in *C. maxima* and *C. moschata*, they are nonhirsute and of soft texture. Yasuda finds that in some varieties, there are areas on the undersides of the leaves where the epidermal cells are two- to three-layered. Such spots appear etiolated.

Flowers.—The plants are usually monoecious, with staminate flowers on long, slender peduncles and pistillate on short, thick, peduncles, occurring singly in different axils. A case of pistillody, involving most of the flowers on a plant was reported by Berkeley (1851). Durham (1925B) found hermaphroditic flowers in certain inbred strains of *C. pepo*. Ninety out of 509 plants possessed some hermaphroditic flowers during a severe drought, but after heavy rainfall, most of the plants returned to the monoecious state. Some hermaphroditic flowers were self-fertile.

The development of the flowers has been described by Kirkwood (1905). The female flowers begin as a lateral outgrowth, the apex of which becomes depressed. Sepals arise first around the margin of the torus, and petals follow on an inner circle, the members alternating with the sepals. Carpels arise and extend upward to form the pistil. Placentae arise as longitudinal, parietal ridges, upon which the ovules are formed. In different varieties, there are varying degress of development of the spongy tissue, which fills the locules of the ovary and invests the seed. The ovary is always inferior. It is usually divided into three locules (sometimes four or five). The edges of the carpels are turned inward and are flexed back toward the outside again, the borders becoming proliferated into two or three longitudinal ridges, and these reflexed margins form the placentae. Ovules borne on these ridges are formed at successive periods, but all develop, so that the opportunity for fertilization is about equal. The stigma (which surmounts the ovary on a short style) has lobes equal in number to the carpels. Calyx tube and corolla are five-lobed. In the staminate flowers, the filaments are free, but the anthers are more or less united into a column-like mass.

Fertilization.—Cummings (1904) observed that Golden Custard was readily fertilized by Summer Crookneck, but that the reciprocal cross was generally unsuccessful or resulted in production of fruits with abortive seed. Of 200 Crookneck × Custard crosses, only 3 per cent gave fruit with some viable seed. Both varieties belong to *C. pepo;* Cummings could find no differences in the pollen or in its germination, between the two varieties. Pollen of Custard germinated on the stigma of Crookneck, but it required 5 to 8 days for the tube to traverse the 1⅜ inches of stylar tissue and reach the embryo sac. The vegetative and generative nuclei pass into the pollen tube the second day after germination; and before the end of the eighth day, the tube nuclei enter the embryo sac and come to rest near the egg cell. In the infertile cross mentioned above, there was no fusion of the male and female gametes, these remaining beside each other for 2 days before degeneration begins. Kirkwood says that the polar nuclei ordinarily fuse before fertilization; the division of the primary endosperm nucleus commences before that of the fertilized egg. It is not known whether double fertilization takes place.

Pollination.—Transfer of pollen is usually accomplished by insects, chiefly honeybees. Because of the monoecious character of cucurbits, there is nearly an equal chance of pollen's being introduced from staminate flowers on another plant as from the same plant, and cross-pollination is common. Furthermore, in some varieties, many of the plants appear to be self-sterile, making necessary the introduction of pollen from another plant (or even from another line). The extent to which self-sterility occurs in this group is indicated by Bailey's (1890) attempts at geitnogamous self-pollination in 50 varieties of pumpkins and squash. He failed usually to secure fruit, and the occasional fruits obtained by self-pollination contained non-viable seed, leading him to conclude that inbreeding in the group was impossible. In 1915, however, Bushnell (1920) secured 47 selfed fruits in the Hubbard variety (*C. maxima*). His practice of removing all pistillate flowers except those pollinated by hand, may have aided in the production of fruits through self-fertilization. The following year, in the progeny of these fruits, nine proved self-sterile and twenty self-fertile. After selfing for two generations, the inbred strains proved to be entirely self-fertile and have continued so. Sinnott and Durham (1922) isolated pure lines of several varieties of *C. pepo.* They found that the tendency toward self-sterility disappeared by the fourth inbred generation.

The flowers are open about 24 hours, and the stigmas are in receptive condition throughout this period. Although pollination is ordinarily accomplished by insects early in the morning, Bushnell (1922) secured successful hand-pollinations at every hour of the day. Pollen applied to the stigma of buds before the corolla expanded did not result in fruit setting; pollination at any time between the stage when the petals

were splitting and when they had begun to wither, resulted in some fruit setting, however. The highest per cent of set was 32, secured from pollination when the flowers were fully open.

Parthenocarpy and Parthenogenesis.—In Naudin's classical work in this genus, five parthenocarpic fruits were obtained. Of fifty varieties of squash, Bailey (1890) found that twenty-two produced parthenocarpic fruits when self-pollinated. These fruits generally contained non-viable or empty seeds (phenospermy). A varying proportion of the seeds in most cucurbits, even when normally pollinated, are of this type. Parthenocarpic fruits have also been obtained occasionally in *Cucurbitae* by other workers, either when no pollen was applied or when incompatible pollen was used, as in species crosses. It is apparent, from the work of Munson and of Cummings, that pollination may stimulate development of the ovary, even though fertilization does not occur.

The Hagedoorns (1924) tested, with negative results, many commercial varieties for the occurrence of parthenogenesis, by preventing pollination from outside sources. The corolla was tied with lead wire in such a way as to exclude insects. When the flowers of F_1 plants of certain intervarietal crosses were enclosed in this way, however, some of them produced fruit with viable seeds. When the F_2 generation was grown from this seed, the segregation of characters in the progeny appeared to be such as to indicate that the seed had really been of parthenogenetic origin. Lotsy (1920) was unable to obtain parthenogenetic seeds in the several species of *Cucurbita*. He did obtain evidence of matroclinal inheritance in reciprocal crosses between *C. pepo* and *C. aurantica*, a fact which suggests that parthenogenesis may have occurred. Durham (1925) thinks that the apparent parthenogenesis reported by the Hagedoorns may have been due to the occurrence of hermaphroditic flowers, which, when enclosed, resulted in selfing.

Fruiting Habits.—The flowering period of a plant extends over several weeks. Only a small proportion of the pistillate flowers produced by a plant form fruit. Bushnell (1922) observed that fruit setting was cyclic, periods of fruit setting alternating with periods when all the buds aborted. Generally, the first flower on a stem aborts, while the second or third usually sets. No correlation was found between fruit setting and size of ovary, method of pollination, time of pollination, or weather conditions. Tapley (1923) found that fruit setting occurred at different periods of development in different varieties. Kitchenette and Quality set a high percentage of the early flowers, while a large-fruited strain of Hubbard aborts most of the early flowers. In others, like Banana, the per cent of set remains about the same throughout the season. Cummings and Stone (1921) observed that high-yielding selections of Hubbard squash produced fewer flowers per plant than low-yielding selections but that the ratio of pistillate to staminate flowers was 1:4 in the former and 1:5.7

in the latter. Their statistical studies indicate a high positive correlation between number of leaves and weight of fruit per plant. "The stronger and more vigorous the growth, the quicker the plant initiates its 'grand period' of growth—an abundance of early foliage may ultimately result in production of more fruits."

According to Tapley (1923), in the varieties Kitchenette, Hubbard, Delicious, Quality, and Banana the number of pistillate flowers per plant ranged from twenty-four to thirty-four. The percentage of these flowers forming mature fruit varied from 43.7 per cent in Kitchenette to 5.5 per cent in Banana, showing an inverse relationship to the number of pistillate flowers. Tapley found a positive correlation between the weight of the mature fruit and the date at which fruit set. In large-fruited varieties, the average weight per fruit decreased at the rate of 1 pound per day, as the season of blossoming advanced. Yield depends, therefore, among other factors, on the ability of the plant to produce a large number of blossoms, to produce these early, and to fertilize a large proportion of the flowers.

Cummings and Stone (1921) found that pruning the vines 2 or 3 feet beyond the second or third fruit resulted in decreased yields, on the average. The removal of all flower buds, however, after two or three fruits had set, increased the size of the fruit slightly.

Fruit.—The weight ranges from 1 to 2 pounds in some of the bush squash to over 100 pounds in some winter varieties. The surface is usually smooth, though a few varieties, such as Summer Crookneck and Hubbard, are warty. The fruits are sometimes longitudinally furrowed, or sutured. Color and shape are extremely variable. The stylar end of the fruit is slightly recessed in *C. pepo* and *C. moschata;* but in *C. maxima*, it tends to be drawn out to a point.

The rind is tender in the immature fruit but, in most varieties, becomes exceedingly hard upon maturation. The mechanical sheath, or stone-cell layer, found in many other cucurbits, is lacking, however. General structure of the fruit is otherwise the same as in *Cucumis*. The endocarp, innermost layer of the pericarp, remains attached to the seed as a thin epithelial layer.

Important constituents of the fruit from the food standpoint are carbohydrates. Dore (1922) reports that the edible portion of Hubbard squash contained 7.8 per cent total carbohydrates, which was 70 per cent of the dry matter. The following distribution of carbohydrates was found: hexoses, 43.2 per cent; pentoses, 1.4 per cent; sucrose, 10.3 per cent; starch, 2.1 per cent; other hexosans, 2.5 per cent; pentosans, 2.0 per cent; cellulose, 7.7 per cent; crude pectin, 6.4 per cent. Glucose is the most important constituent. The amount of this may vary with maturity and length of time fruit is in storage. Some of the large-fruited varieties are often used as stock feed. Lindsey (1917) found that

pumpkins grown in Massachusetts consisted of 17 per cent rind, 73 per cent flesh, and 10 per cent seed and placenta. When the entire fruit was chopped and dried, it contained more protein than did cereals and was also very high in carbohydrate. Feeding trials on sheep showed that pumpkins have 20 per cent greater food value than have mangels or turnips. Contrary to an idea prevalent among farmers, the seed had no ill effects on cattle, when consumed with the whole fruit.

Climatic Requirements

Plants are tender to frost. As they grow rapidly and the fruit of many varieties reach edible size in a short season, they are cultivated even in the most northerly states. In the South, bush squash is extensively grown during the spring for shipment north. In the central and northern states, the long-keeping varieties are grown and stored for winter marketing.

Cultural Practices

Bush squash is produced according to the same methods as cantaloupe. Seed is planted in hills about 3 by 5 feet apart. Pumpkins and winter squash are handled more like watermelons. In regions of ample rainfall this type is frequently grown as an intercrop in corn fields.

Starting the plants in pots in hotbeds and transplanting to the field as well as other methods of forcing maturity are often resorted to for bush squash, since the early product commands high prices. In the Merced district of California, bush squash is planted in the field in early spring, and the plants are protected from frost by covering at night with empty packing boxes.

Harvesting.—Bush or summer squash are used as a fresh vegetable, and fruit is harvested in the immature condition, before rind or seed have begun to harden. Indentation with the thumb nail is the common test as to suitability of the fruit for use. White Bush squash is in the best edible condition when the fruit is about 3 inches in diameter.

Winter squash and pumpkins are allowed to ripen on the plant and are generally not harvested until the foliage has been killed by frost. The more mature the fruit at harvest time, the higher the sugar content and the better the keeping quality.

All kinds of squash are harvested by cutting the peduncle so that a short stub is left adhering to the fruit. Abrasions in the fruit are to be avoided.

Marketing

Summer squash, including scallops, Summer Crooknecks, and Cocozelle, are marketed during spring and summer, being trucked to

nearby markets or shipped with other vegetables in mixed cars. Standard barrels are the chief containers used in the South, while 30- and 40-pound lug boxes are used in California. Winter squash and pumpkins are either marketed direct from the field in the autumn or are placed in storage. They are usually handled in bulk, though the smaller types are often sacked. When being sent to canneries for immediate use, they are generally shipped in bulk in coal gondolas.

Storage.—For storage purposes, winter squash and pumpkins must be fully matured on the plant. The fruit must be carefully handled, to avoid bruising and breaking the peduncle at its place of attachment to the fruit. A period of field curing, after harvest and before removal to the storage house, is considered desirable. Squash should be stored in a dry, warm room. Golden Hubbard has been kept in perfect condition for over a year under such conditions. Squash-storage rooms should be well insulated and provided with facilities for ventilation and for heating. The fruit is placed on shelves in layers one or two deep. Accumulation of moisture on the surface of the fruit is conducive to invasion by soft-rot organisms. Stuart (1907) stored Hubbard squash in Vermont, from Oct. 3 to Feb. 3, in a dry room at 10 to 15°C., with a total loss in weight of 20.8 per cent and by decay, 4.8 per cent. Shrinkage is due to loss of water by evaporation and of carbohydrates through respiration. Hood (1919), in Nebraska, stored the same variety at 4.5 to 10°C. from Nov. 1 to Apr. 1 and found that the average loss in weight was 23 per cent. Shrinkage varied from 10 to 40 per cent for different individual fruit, this wide dissimilarity being attributed to difference in maturity at the time the fruit was harvested. He showed also that the rate of shrinkage tends to increase toward the end of the storage period, being 3.7, 1.3, 4.4, 4.1, and 9.5 per cent, respectively, for the months of November to April. The increased price received for the stored product generally more than balances loss by shrinkage and cost of storage.

Canning.—Both pumpkins and winter squash are canned extensively, being always marketed as "pumpkin." This product is used mostly as pie stock by the bakery trade. Its canning is centered in California and Oregon. Italian Cheese pumpkin and Boston Marrow squash are the varieties most used for canning, the former producing somewhat larger yields but of poorer quality. Color and texture of flesh are the most important qualities from the canner's viewpoint. Yields are expected to average 20 tons per acre, and the price to the grower is about $5 per ton. The seeds, placenta, and rinds are valuable by-products. They may be dried cheaply, ground, and marketed as feed for cattle. Masurovsky (1921) finds that the ground seed or the fresh cannery waste may be fed to young hogs in unlimited quantity without injurious effects.

Dehydration.—Pumpkins and squash are dehydrated to some extent. In 1921, 4,357 tons were dehydrated in California alone. Chris-

tie (1922) has worked out methods for the dehydration of pumpkins and the manufacture of flour therefrom.

Varieties

The varieties of squash and pumpkins listed in American seed catalogs are very numerous. Ease of cross-pollination and the large number of varietal characteristics in this group lead to the constant appearance of new forms. In 1887, Goff (1887) classified all varieties into twelve groups, using fruit characters as a basis. Many varieties grown at that time have disappeared from cultivation, and new ones have been introduced. Recently, Castetter (1925) studied 67 varieties and divided them into 17 groups, distributed among the 3 species, as follows:

I. **Cucurbita pepo:**

1. *Field or Pie Pumpkin.*—Yellow, grooved fruits, oblong, round, or flattened at both ends. Varieties of this group are very similar, except that the Mammoth Tours are mottled green and yellow, and the Sandwich Island is vegetatively much coarser. Other members are: Connecticut Field, Kentucky Field, Small Sugar, Winter Luxury, Fort Berthold, Golden Oblong, Omaha.

2. *Scallop.*—Fruit flat, scalloped around the edges, color white or yellow, plants of bush type. Examples are Early White Bush, Mammoth White Bush, Long Island White Bush, Early Yellow Bush, Golden Custard, Early Mandan (the latter is not scalloped).

3. *Summer Crookneck.*—The fruit is elongated, with a curved neck and warty surface. Plants are of the bush type. This group includes Yellow Summer Crookneck, White Summer Crookneck, Giant Summer Crookneck.

4. *Vegetable Marrow.*—The fruit is elongated and club shaped, tapering to the stem end. The color is white, green, or striped. Used only in the immature condition, being somewhat earlier than the scallop. Bush, semi-bush, and trailing forms occur in this group, which includes Cocozelle, Zuchini, Green Vegetable Marrow, Long White Marrow, White Vegetable Marrow.

5. *Fordhook.*—The fruit is short, club-shaped, and longitudinally grooved. Used as winter varieties. There are both bush and trailing forms. Includes Fordhook, Fordhook Bush, Delicata, English Cream Marrow.

6. *Table Queen.*—Fruit small, acorn shaped, and deeply grooved. Used as Winter squash: Both bush and trailing plant types exist. Includes Table Queen, Des Moines, and Panama.

II. **Cucurbita maxima:**

7. *Hubbard.*—Fruit spherical in the middle, tapering to a curved neck at stem end and to a somewhat curved point at blossom end, with very hard shell. The surface of the fruit is more or less warty, and the

color of the skin varies among varieties. This group contains only trailing plant types. Used only as winter squash. Representatives are Blue Hubbard, Chicago Warted Hubbard, Golden Hubbard, Green or Improved Hubbard, Kitchenette, Marblehead, Arikara.

8. *Delicious.*—Fruit cone shaped, hard shelled, with trailing plants. Color varies between varieties. Includes Delicious, Pikes Peak, Winnebago.

9. *Orange Marrow.*—Fruits lemon shaped, ranging from light to reddish orange in color, and with irregular surface. The varieties are Boston Marrow, Early Golden Marrow, Orange Marrow.

10. *Turban.*—The fruit are turban shaped and characterized by an enlarged button at the stylar end. Representatives are Essex Hybrid, Bay State, American Turban, Turkenbund.

11. *Banana.*—Fruit elongated, somewhat pointed at both ends. The shell is soft and of a greyish-green color. Banana, Plymouth Rock.

12. *Pebbled.*—The skin is of deep-orange color, and the shell very thick, hard, and extremely warty. Warren, Victor.

13. *Show Squash.*—This group contains a number of very large, soft-shelled varieties, used chiefly for show purposes, as King of the Mammoths, Mammoth Chili, Atlas, Mammoth Whale, Estampes.

III. **Cucurbita moschata:**

14. *Large Cheese.*—The varieties vary in shape, but all have creamy-buff color, smooth skin, a thin, hard shell, with hard fruit stalk, which flares conspicuously at the attachment to the fruit. Includes Large Cheese, Quaker Pie, French Cocoanut.

15. *Cushaw.*—Smooth, variously colored, soft-shelled fruits with long, curved necks. Representatives are Striped Cushaw, White Cushaw, Mammoth Golden Cushaw, Small Golden Cushaw.

16. *Pear Shaped.*—The fruit have smooth skins and thick fruit stalks. Includes Japanese Pie, Tennessee Sweet Potato.

17. *Miscellaneous.*—Varieties not belonging to the above groups. (Winter Nut, Chirimen, Faxon's Brazilian, Ironclad.)

Breeding

Much of the earlier genetic work on squashes failed to yield reliable results, because of the heterozygous nature of commercial varieties used as parental material. Sinnott and Durham (1922), by selfing for three generations, isolated several self-fertile strains of the summer squash, which seemed to be homozygous and were used as parents, to study the mode of inheritance of various characters. These results may be summarized as follows:

White body color of fruit dominant over yellow and yellow over green. Solid skin color (plain or self-colored) dominant over striping, in most cases.

Wartiness is due to two independent factors cumulative in their effect and dominant over absence of warts, or smooth surface.

Disc fruit shape dominant over spherical, the main difference being due to a single factor, but one or more additional factors may produce minor effects.

White flesh is usually dominant over cream and over salmon color.

Single dominant over double blossom scar, though this is modified by environment.

Habit of plant, shape of leaves, internal fruit characteristics, size, shape and color of seed, depth of stylar scar, and many other factors appeared to be hereditary, but the mode of inheritance was not determined.

From a cross between a long crookneck (Striped Spoon) by a short, thick-fruited variety (Filipino Horned), Emerson (1910) obtained fruits in the F_1 generation longer than the longer parent and in the F_2, a great variability of forms, some being even longer than the F_1. He concluded that size and shape of fruit were not simple characters but that a particular size or shape depends upon two or more genetic factors some or all of which may exhibit incomplete dominance. Sinnott (1922), as a result of his crosses between spherical and flat-fruited pure lines, which showed definite evidence as to the dominance of the latter, concluded that shape-determining factors do exist and that the results in shape inheritance are not to be confused with segregation of size factors. Becker (1922), however, obtained opposite results between long and short forms of other varieties. Drude (1918) seemed to find many characters to be not inherited in Mendelian fashion, and often reciprocal crosses gave different results, probably due to the heterozygous nature of the parents. From a cross of two lines having round fruit, Sinnott (1926), in F_2, obtained disc, round, and long fruit in 9:6:1 ratio, indicating that two factors are involved, each tending to flatten the fruit and cumulative in their effect. Where both are absent, the fruit is long.

From the practical standpoint of improvement of squashes, isolation of pure lines through inbreeding existing varieties seems to be much more important than origination of new types by crossing. Drude found it very difficult to secure self-fertilized seed in *C. pepo*, and when this was successful, it led to loss of vigor and to self-sterility. He was able to maintain his lines by crossing sister plants (close-pollination). On the other hand, Bushnell (1922) isolated a large number of self-fertile lines from the Hubbard variety, which showed little or no loss of vigor as a result of the inbreeding, as shown by the following results as to yield:

	Kilograms per Plant
Average for six lines inbred four generations	11.6
Average for seven F_1 hybrids between inbred lines	12.2
Average for six commercial lots	12.3

The lines isolated by inbreeding differed from each other in size, shape, and other fruit characters but were remarkably uniform for these characters within the line after two generations of inbreeding. One of these strains has been introduced as the Kitchenette variety.

Cummings and Stone (1921) made selections within Hubbard for quality and yield. Continuous selections for high and low yield, maintained over a series of 6 years, resulted in a good contrast in yield, regardless of the method of pollination. Open-pollinated selected lines gave gains of 26 to 102 per cent in favor of the high-yielding selection, the maximum gain coming in the fourth year. The increased yield was due both to increased number and to increased size of fruit. Intercrossing did not affect yields appreciably as compared to self- and close-pollination. While the quality of the fruit depends, to some extent, on such factors as soil, season, and maturity, Cummings and Stone showed that heredity was also an important factor. They isolated by selection, strains which were of uniformly poor or good quality. The latter contained more carbohydrates but less water and less protein than did the poor strains. Fruits of low quality contained only 3.41 per cent total sugar, on the average; while high-quality fruit contained 5.4 per cent. High quality was said to be associated with full maturity, hard, thick shell, clear color demarkation between flesh and shell, and relatively few seeds but was not usually accompanied by large size of fruit. Cummings introduced a small-fruited strain under the name, "Vermont Hubbard," in 1925.

Diseases

Squashes and pumpkins may be attacked by bacterial wilt, mosaic, powdery mildew, and other diseases common to the *Cucurbitaceæ* in general, diseases which have already been discussed. There is also a wilt disease caused by a species of Fusarium, which attacks only squash, *F. cucurbitae*. Taubenhaus (1920) reports that the Sugar-through gourd is immune to this wilt. Pumpkins tested by Taubenhaus proved, moreover, highly resistant to Fusarium wilt, while the summer and winter squashes were susceptible.

Insects

Spotted and striped cucumber beetles and melon aphis, which also attack pumpkins and squash, were discussed under cantaloupe (see p. 431).

Vine Borer (*Melittia satyriniformis*).—The vine borer attacks squash most severely. Larvae tunnel in the basal part of the stems, causing the plant to wilt and turn yellow. This insect does not attack early varieties but is one of the chief enemies of winter squash. It passes the winter in the ground in the pupal stage. Fall plowing, which exposes many of the pupae, aids in control. The adult moths emerge in June or July and

lay their dull, red eggs on leaves and stems of squash plants. The larvae hatch from these eggs a few days later and bore into the stems. Worthley (1923) obtained a 97 per cent control by destruction of the eggs with a nicotine spray, using Blackleaf-40, 1: 100 parts of water. The 1: 250 strength was nearly as effective. Four applications at weekly intervals, after the adult moths appear, are necessary. Gathering and burning the dead vines will destroy many larvae within them and limit later infestations. Removal of the borers with a knife and mounding the stems with earth are useful when the borers are few.

Squash Bug (*Anasa tristis*).—The squash bug, often referred to as "stink bug," on account of its offensive odor, is especially common on squash. Adults are large, sluggish, brown or black, sucking insects. They overwinter in trash piles. Both adults and nymphs cause extensive injury to plants. The eggs are laid in large masses on the undersides of the leaves and may frequently be observed and destroyed. The young nymphs, emerging from these eggs, begin feeding at once. In this stage, the insects are soft-bodied and readily killed with contact insecticides. Wadley (1920) found that all nymphs and a very large portion of the adults could be killed by spraying with Blackleaf-40, 1: 250, or with fish-oil-soap solution, 1 pound: 4 gallons of water, with the addition of a little sulfur.

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CHAPTER XXIII

CITRULLUS

The watermelon crop occupies a large acreage but is comparatively low in value of the product per acre. Watermelons are grown mostly on a field scale, in the southern and central states and in California. They occupy a prominent position in the shipments of seasonal fruits and vegetables. Their popularity is peculiarly American—in no other country is watermelon so extensively consumed.

Taxonomy.—Of the four species of Citrullus, only two are of economic importance. *C. colocynthis*, the bitter gourd, or colocynth, is native to North Africa, producing small, non-edible fruits, from which a drug is extracted. *C. vulgaris* includes the watermelons and the stock, or citron, melons.

History.—Watermelons came into cultivation in rather recent times, being apparently unknown in Europe until the sixteenth century. They are usually considered to be native to Africa. Livingston (1858) found them growing in central Africa, in regions not previously visited by white men. Carrier (1924), however, finds evidence that watermelons were native to North America, for early French voyagers came upon Indians growing watermelons in the Mississippi Valley. Judging from their description, the native American sorts may have been like our citron melons, while true watermelons came originally from Africa. As early as 1629, the latter were extensively grown in New England (Sturtevant, 1919). Central Asia and other Oriental countries have been the source of introduction of some varieties. The numerous varieties now grown in this country have probably all been developed here, by selection from older types.

Plant Characteristics

The plant, in general, resembles that of the genus *Cucumis*. The stems, however, are angular in cross-section, and the leaves are cordate at the base, pinnately divided into three or four pairs of lobes, which are, in turn, lobed and toothed. Schaffner (1903) observed a plant with entire leaves, which originated as a mutation in one of the common varieties.

Kartashov (1925) found that the root system is very extensive but shallow. Most of the roots were within 1½ to 2 feet of the surface. Lateral roots of the first order grow parallel to the surface and exceed in

their development the central, or tap-root. The roots develop rapidly; seedlings 2 weeks old were found to have tap- and lateral roots 7 inches long. Later, the lateral roots exceed the stems in length.

FIG. 84.—Terminal portion of watermelon stem, showing floral arrangement. A. Staminate bud. B. Staminate flower. C. Staminate flower, 1 day after anthesis. D. Pistillate flower two days after anthesis. E. Forked tendril.

Flowers are smaller and less showy than in *Cucumis*. They are located, singly, in the axils. Some varieties (Angeleno, Chilian, and Winter Queen) bear hermaphroditic and staminate flowers; most varieties, however, are monoecious, bearing purely staminate and pistillate flowers.

The pistillate and hermaphroditic flowers occur in every seventh axil, the intervening axils being occupied by staminate flowers. The corolla is greenish yellow, united in a tube, deeply five-lobed. The three stamens are inserted at the base of the corolla.

Pollination.—Watermelons are generally insect-pollinated. The hermaphroditic flowers are potentially self-fertile, but pollination does not take place unless they are visited by insects. In varieties having pistillate flowers, the transfer of pollen to them from the staminate flowers is performed chiefly by bees. This method of pollination naturally introduces opportunity for extensive cross-pollination. As a result, watermelons generally show considerable variability within the variety.

The flowers open 1 to 2 hours after sunrise. The pistillate flower and the staminate flower in the axil just below it open the same day. The anthers have dehisced when the corolla expands, but the pollen remains on the anthers in sticky masses. The stigma is receptive throughout the day. Late in the afternoon, the corolla closes and is withered by the following morning. If the stigma has not been pollinated, the ovary may continue enlarging for several days before degeneration sets in, but mature parthenocarpic fruits do not occur.

Fruiting Habit.—All of the pistillate or hermaphroditic flowers do not develop mature fruits; most of them degenerate soon after fertilization. There does not seem to be a definite cyclic occurrence of fruit setting, as in the cantaloupe. Fruits set more or less irregularly throughout the season or, at least, as long as the plants are growing vigorously.

Fruit.—The fruits are large, ranging from an average weight of 10 to over 50 pounds, in different varieties. The shape is also variable, being round, oval, oblong, elongate-cylindrical, or elipsoidal, in different varieties. The color varies from white to various shades of green, frequently mottled or striped. The rind is firm but not hard, green near the surface, white within, and changing gradually to the pink, red, or yellow fruit flesh when ripe. In the flesh are embedded the numerous white, red, green, brown, black, or mottled seeds. They are flat, not bordered, lustrous, and smooth except when mottled, in which case the surface is slightly rough.

The greater portion of the fruit is the edible flesh, which is mostly derived from the placentae, instead of from the pericarp or rind, as in the cantaloupe and squash. The locules are clearly outlined, and, when very ripe, the flesh may separate along these lines, but no true cavity is formed. The hard outer portion of the fruit—the rind—is pericarp, which is divided into successive layers (Miss Barber, 1909). The outermost layer—the epidermis—is a single transparent layer of flattened cells, the outer walls of which are very much thickened; stomata are numerous, occurring singly, or in groups; below the epidermis is the hypoderm, many cells thick and containing chlorophyll, forming the

green tissue of the rind. The next layer is the mesocarp the outer portion of which consists, in the young fruit, of small, isodiametric cells, which gradually thicken their walls during maturation, become sclerenchymatized, and, some of them, develop pits. This type of cell increases in number as the fruit matures, until there is finally a distinct zone of stone cells just within the hypoderm and almost completely surrounding the inner tissues. This sclerenchyma sheath gives the rind its hard, tough texture. In the middle portion of the mesocarp, the cells are likewise

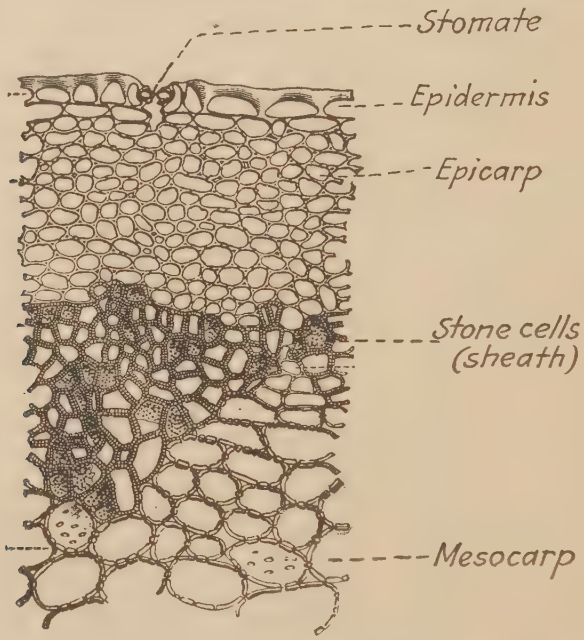

FIG. 85.—Section through the rind of watermelon fruit. (*After Miss Barber.*)

thickened and pitted. They gradually increase in size toward the interior. The inner mesocarp merges into the colored flesh, the cells of which are very large. Walls are thin and separated at the angles by intercellular spaces, filled with a sweet, watery liquid. The mesocarp is traversed throughout by vascular bundles, sieve tubes, and latex tubes.

Composition.—Van Slyke, *et al.* (1905), give the following as the composition of watermelons grown in New York:

TABLE 78.—COMPOSITION OF WATERMELONS, IN PER CENT OF FRESH WEIGHT (*Van Slyke, et al.* 1905)

	Water	Nitrogen	Phosphoric acid	Potash
Fruit	92.9	0.167	0.055	0.306
Stems and leaves	84.5	0.501	0.074	0.496

The ripe fruits contain from 5 to 7 per cent sugar, which is over half glucose, according to Crocker (1895). In the juice of white-fleshed fruit, he found 2.91 per cent glucose and 2.16 per cent sucrose; in red-fleshed fruit, 3.57 to 3.84 per cent glucose and 1.77 to 2.18 per cent sucrose. The high sugar content and the ease with which the juice is extracted permit the use of small or otherwise unsalable melons for the manufacture of syrup. The juice is extracted by pressing, then concentrated by evaporation, the ratio of juice to syrup being about 13: 1. Watermelon seeds are used as food by the Chinese.

The claim is often made that K, applied in manures, favorably affects the flavor, quality, or sugar content of watermelons. Literature does not afford any evidence for such belief, however, though K is a nutrient no doubt profitably applied in some cases. In Georgia, Stuckey (1924) finds that, while the yield, earliness, and size of fruit may be influenced by various manures, no constant differences in quality could be attributed to them.

Climatic and Soil Requirements

Climate.—The watermelon is tender to frost and requires a long growing season with high temperatures, for best growth and quality. Important producing districts are found as far north as New Jersey, however, on the Atlantic Coast, eastern Iowa in the Mississippi Valley, and the Yakima Valley of Washington on the Pacific coast. While some varieties will mature even in Canada, the fruit are small and of poor quality, as compared with the southern-grown melons. Watermelons are not so markedly affected by atmospheric humidity as is the cantaloupe. From the standpoint of both flavor and shipping quality, it is produced equally well in the humid climate of the Southeast and in the arid climates of Arizona and California. Foliage diseases are much more destructive, however, under conditions of high humidity. This fact is reflected in the lower yield per acre and in the wide fluctuation of yields from year to year, in humid districts.

Soils.—The chief watermelon districts are, without exception, characterized by light, sandy soils. These are often deficient in necessary nutrient elements but, when properly manured, are ideal for the crop. There is a marked correlation between soil types, plant growth, and quality of fruit. While watermelons are sometimes grown on heavy soils the development of the plant and the size and quality of the fruit are usually inferior.

Watermelon is tolerant to soil acidity. Hartwell (1914) found that the best yields were produced on soil made very acid by applications of sulfate of ammonia for several years. Lime injured the plants under these conditions. The crop is grown successfully, however, in slightly alkaline soils in California. In the South, watermelons grow best on

land the first year or two after it has been cleared from the forest. The high content of organic matter, the tendency for such soils to be rather acid, and the freedom from insects and diseases are probably the factors which favor watermelon production on virgin soil.

Cultural Methods

Planting.—Planting in the field usually commences as early as soil becomes warm enough to germinate the seed. Watermelons are somewhat more hardy than cantaloupe.

The same planting methods are followed for watermelons as for other melons, but more space is allowed to the plant. In the East and South, planting is either in hills about 10 by 10 feet apart, with two plants per hill, or in rows 10 feet apart with single plants spaced 2 to 3 feet apart in the row. The latter method gives more plants per acre, a better distribution of the plants, and is better adapted for large plantings, where most of the cultural operations are performed with machinery. In irrigated districts, the planting is either in hills or in drills on the side of the furrows, about 10 feet apart.

Care of Crop.—An excess of seed is always planted, to insure a full stand. When they develop the first true leaves, the plants are thinned. Under irrigation, as the vines begin to develop, they are trained away from the water furrow. Elsewhere, they are trained to fill the row in one direction, usually parallel to that of the prevailing winds. This leaves between the rows an open space, which facilitates late cultivation and harvesting. Mounds of earth may be placed over the vines near the tip, after they are "turned," or trained in position. These prevent their being blown about by high winds; roots may develop from the nodes of the mounded portion.

When the fruits are developing, many growers remove all imperfect ones—"goosenecks" and "nubbins,"—so that the resources of the plant may be utilized more fully in the development of the perfect fruits. These imperfections are probably due to inadequate pollination and result in fruit worthless for marketing. In some cases, only two fruits are allowed to develop on each plant, on the theory that size and earliness will be increased by limiting the number.

Special efforts to advance the maturity of the crop are not generally practiced with watermelons, because of their low acre-value. Protection of early-planted seed in the field, with paper caps or other forcing devices, is practiced to some extent. Watermelons are often protected by sowing strips of rye or barley across the fields the preceding fall, at intervals of every four or five rows. These strips usually run from east to west and protect the young plants from cold winds.

Irrigation.—Though the watermelon is a native of semi-arid regions, liberal moisture supply throughout the growing season is desirable. Most

of the melons grown in the West are produced on either surface or subirrigated land. With a liberal moisture supply, the plants continue to produce fruit of large size over a long season. They are usually started with the natural moisture supply from winter rains, though irrigation is sometimes commenced as soon as the plants are up and continued at intervals throughout the growing season, applying 1½ to 3 acre-inches of water at each irrigation.

Harvesting.—Neither size of fruit nor color of rind bears any relation to ripeness. There are external indications, however, which are of use in determining the maturity of fruit: (1) The tendril which subtends the peduncle of the fruit usually withers as the fruit ripens, though this is not true of all varieties; (2) the soil spot, or area of the fruit which resist on the soil, turns from white to creamy yellow upon maturity; (3) the rind at the soil spot, which is tender while the fruit is immature, becomes so tough that it is not easily dented with the thumb nail; (4) upon rapping the melon with the knuckles, a hollow sound indicates immaturity and a dull, heavy sound denotes ripeness; (5) upon pressure of the melon with the flat of the hand, a crisp, cracking noise within the fruit indicates ripeness. This last test is injurious when the melons are to be shipped. All tests vary somewhat with different varieties, different climatic conditions, and different times of day. Early morning is the best time to pick melons, both from standpoint of determining ripeness and of securing the best quality. The turgidity of the fruit favors retention of the crisp texture of the flesh.

Many melons are shipped to market unripe, due partly to carelessness on the part of the pickers and partly to the idea prevalent among growers, that melons intended for shipment should be harvested in the immature condition. There is, however, little difference in the degree of ripeness required for a good shipping watermelon and one for immediate use. Color, sugar content, and flavor, chief attributes of a ripe watermelon, do not increase appreciably after it has been picked, though there is a gradual softening of the pulp around the seed. When harvested ripe and handled carefully, watermelons will keep satisfactorily from 3 to 4 weeks, in a cool place. This fact makes possible the shipment of watermelons without refrigeration from southern fields to northern markets.

Marketing

Shipment.—Ordinary box or cattle cars, in which the sides have been stripped to a height of 3 to 4 feet, are used for shipping watermelons. On the bottom of the car is placed a layer of straw about 1 foot thick, and on this the melons are stacked in regular tiers. The smaller grades are loaded five tiers deep; and the larger (over 24 pounds average weight), four tiers deep. The number of melons per car ranges from about 1,500 for 18-pound melons to 700 for 35-pound fruit.

Small varieties, such as the Klondyke, and very early melons shipped in less than carlots are sometimes packed in crates or barrels lined with excelsior.

Grades.—No standard grades for watermelons exist, size being the chief factor on which prices are based. The average weights in common use as grades are 18, 20, 22, 24, 26, 28, 30, and 35 pounds. A range of 4 pounds above and below the average weight is allowed.

Size generally bears an important relation to price. Pacific coast markets prefer the smaller size, while on most of the eastern and northern markets, where there is a great demand for fancy melons for restaurant trade, the price per pound increases with the size of the melons.

The demand for large melons should govern the grower's cultural practices to a large extent. Size can be increased by allowing the plants more space or thinning to a single plant per hill; removal of imperfect fruits early in the season; heavy manuring; and selection of large-fruiting varieties, or strains.

Factors Affecting Prices, Demand, and Consumption.—The earliest melons reach the markets in May and bring fairly high prices, but there is little demand for this fruit in the North, until warm weather arrives. This usually results in higher prices, but heavy shipments gradually saturate the markets of the country, and prices decline rather rapidly during June. The weather in the chief producing regions influences the volume and quality of shipments, and in the northern cities, it influences demand and consumption. Supply, quality, and prices of other seasonable fruits also affect the demand. Watermelons are the summer luxury of the laboring class, and consumption falls off when unemployment or low wages prevail.

Wholesale prices for watermelons from the early southern districts usually reach the low point for the year at about the end of the season of shipment, in July. Prices improve somewhat as shipments commence from the later districts.

Producing Regions and Shipping Seasons.—Acreage in different sections fluctuates widely from year to year. The average price per carload varies among different states, because some states ship most of their crop in early summer, when prices are generally high. There are marked variations in the average yield of different states. In general, in the West, where the crop is grown under irrigation, the soil is comparatively fertile, and insects and diseases are not serious, and thus, the yield per acre is higher than it is in the East. This difference, however, is not so marked as in the case of cantaloupes, and it is not likely that watermelon culture will ever become so concentrated in the Southwest. The comparatively low value per carload does not permit the high transportation charges required to ship watermelons a very great distance to market.

Table 79 gives the carlot shipments of watermelons from the most important states.

TABLE 79.—SHIPPING SEASON AND CARLOT MOVEMENT OF WATERMELONS FROM LEADING PRODUCING REGIONS

State	Shipping period	Carlot shipments				
		1922	1923	1924	1925	1926
Alabama	July, August	1,941	1,256	2,278	1,880	1,875
California	June to October	4,302	4,054	4,305	4,522	6,273
Florida	May to July	11,341	4,317	6,355	7,190	8,277
Georgia	June to August	13,418	7,222	16,347	14,754	19,391
Missouri	July, August	2,752	1,783	1,432	3,293	2,915
North Carolina	July, August	993	1,542	664	991	1,130
South Carolina	June, July	4,677	4,009	4,972	4,232	5,290
Texas	June to August	4,203	5,317	6,513	3,157	6,223
Total		47,625	33,029	45,745	44,184	54,705

The earliest and one of the largest shipping districts is at Ocala, Florida. Carlot movement commences here in early May and continues until the latter part of June, the shipping season overlapping somewhat that of the Thomasville district in southern Georgia. In central Georgia, around Macon, the peak is usually reached about the middle of July. Somewhat later, heavy shipments move from the sand hill section in the central part of North and South Carolina. Maryland and Delaware ship during August.

A similar series of districts from south to north is found in the middle part of the country. At Hamptead, Texas, shipment is chiefly in July. In northern Texas, around Sulphur Springs and Omaha, the crop is later. Southeastern Missouri is one of the principal late-shipping districts, most of the movement being in August.

In the West, Imperial Valley ships a large volume of early watermelons, supplying Pacific coast and intermountain states during May and June. In July, the Turlock district in central California commences to ship in large quantities and continues as long as there is any demand for melons, which is usually early in November. This district has the longest shipping season and largest yields per acre for watermelons of any district in the United States. The Yakima Valley, in Washington, ships heavily toward the end of the season.

Shipments of watermelons are chiefly from south to north. Few Middlewestern melons reach the eastern markets, and California shipments seldom go further east than Denver.

Varieties

Market requirements are rather definite. Varieties having deep-red flesh and black seeds are preferred, because of popular association of those characters with best eating quality. Eastern markets prefer a long, cylindrical fruit, which is conveniently piled in tiers, rather than a short round type. Pacific coast markets prefer the latter. Fruit having a uniform color of rind, either light or dark green, is always preferred to that having striped or mottled patterns. Most markets demand fruit of medium to large size. Solidity of flesh and strength of rind are essential in a good shipping melon. Some varieties, which have high table quality, are lacking in some of the above essentials. Such are grown for home use and local markets.

The list of watermelon varieties is long, but only a limited number are of more than local importance. Rane (1901) classified them into six classes, according to color and pattern of markings on the fruit: (1) uniform light green (grey), (2) uniform medium green, (3) uniform dark green, (4) striped light green, (5) striped dark green, (6) mottled. Within each of these groups there are many varieties of diverse shapes, sizes, and other characteristics. The more important are as follows:

Tom Watson.—This is generally considered to be the best variety for shipping purposes, though it is not always the one which receives the highest price. It is grown very extensively in the southern and central states but is not important in California. The fruit is long, cylindrical, of uniform-dark-green color, and, in the majority of cases, medium to large. The flesh is deep red when ripe; and in pure strains, the seed is brown. Shallow, longitudinal grooves in the fruit also characterize the best strains. The rind is thick and strong.

Irish Grey (Sweetheart).—The fruit is long, and cylindrical but tends to be smaller toward the stem end. It is light-yellowish green in color, with a network of fine lines over its entire surface. The flesh is deep red, and the seed is white. The rind is thin but tough, and the fruit ships well. Since 1920, this variety has attained considerable popularity on northern markets, commanding a higher price than Watson.

Kleckley Sweet.—The fruit is oblong in shape, dark green in color, and large in size. The seed is white, and the flesh is bright red, firm, solid, and of excellent quality. This variety is one of the best for home use, but it does not ship well.

Florida Favorite.—The fruit is long, cylindrical, and light green in color, with heavy, irregular, dark-green, longitudinal stripes. The flesh is pink, and the seed is white. It is a rather late-maturing variety, grown for local markets in the South.

Klondyke.—The Klondyke variety is important in California. Its fruit is small, averaging about 20 pounds, oblong with rounded ends, and has a uniform-light-green rind, which is longitudinally grooved. The

flesh is pink. The seed is about half as large as in other varieties and is usually mottled. Black-seeded lines have been isolated by inbreeding and selection. This variety is generally considered of very high quality but not especially well suited to shipment, because the rind is not very hard.

Angeleno.—There are both black- and white-seeded strains. The former is an important variety for shipping in the West. The fruit is rather small and nearly round, with a smooth, dark-green surface. The rind is rather thick and very strong. The flesh is very deep red, firm, and medium sweet.

Stock Melon, or Citron.—Although belonging to the same species as watermelon, with which it readily crosses, the citron is inedible and is distinctly different as to fruit characteristics. It should not be confused with the citron of commerce, derived from a citrus fruit (*Citrus indica*).

The plant is very hardy and matures its fruits in nearly all parts of the United States. In California, it has escaped from cultivation and grows wild. It is cultivated to a limited extent in the North for making preserves, also for use as stock feed. The fruit is very low in nutritive value, containing only 0.7 per cent protein, 3.3 per cent digestible carbohydrates, and 0.2 per cent fat, being equivalent to about $\frac{1}{12}$ its weight in alfalfa hay. An interesting feature is the high content of pectin, which is sometimes extracted and used to bring about jell formation in fruit juices which lack pectin.

Breeding

Little systematic breeding of watermelons has been done, the many varieties having originated from selections of chance crosses. Most or all varieties are really mixtures of strains, which breed true for the general variety type but differ in minor characters. There is need for the isolation of pure lines from leading commercial varieties, in order to secure types which are uniform in such essential characters as size and shape of fruit, color and quality of flesh, color of seed, and time of maturity.

The principal work on watermelon breeding has been done by Orton (1908), in his efforts to develop a variety resistant to Fusarium. Crossing the non-edible, wilt-resistant citron with the edible, wilt-susceptible variety Eden, he secured F_1 plants which were exceptionally vigorous and intermediate in type between the parents. Several thousand plants were grown in the F_2 generation. Segregation of characters, occurring in this generation, resulted in plants of many different types. Selections were made in this progeny for several years, and finally, a wilt-resistant, edible type was secured, thus combining the two parental characters sought. This resistant variety, Conquerer, has not proved suitable for commercial purposes, however. It is an oval, striped melon, with pink flesh and white seeds.

Seed Production

An immense amount of seed is required to plant the annual acreage of watermelons in the United States. Most of this seed is produced in Florida, though large quantities are grown in Iowa, Colorado, and California. Much of the cheaper seed is saved from commercial fields after the shipping season is over, but the better seed comes from commercial fields grown especially for seed purposes. Fruit intended for seed production is left on the plants until fully ripe. It is then piled in windrows, a pulping machine is driven through the field, and the melons are pulped. The seed is separated by flotation. In black- and brown-seeded varieties, the pigment does not develop in the outer layer of the seed coat until the latter is fully mature. Seed from immature fruit is mottled or pale in color, though it may be viable.

Fig. 86.—Watermelons grown for seed. The fruit have been windrowed for threshing.

In growing watermelons for seed, expense must be reduced to a minimum, because of the low cash value of the product. Precautions should be taken, however, to assure a satisfactory grade of seed. Most important are the use of carefully selected stock seed and roguing to eliminate off-type plants. Volunteer plants of other varieties and all citron melons in the vicinity should be destroyed. Only one variety should be grown in the field, because of the ease of cross-pollination, The amount of crossing may be considerable, unless varieties are a mile or more apart.

Diseases

Fusarium Wilt.—A wilt disease caused by soil-inhabiting species of *Fusaria* is one of the limiting factors of watermelon production in certain districts. This disease is recognized by a yellowing of the foliage and a dark-brown discoloration produced in the wood of the stem. *F. niveum*

is the species generally associated with watermelon wilt, but, according to Taubenhaus (1920), there are at least two other species attacking watermelons. Watermelon-wilt organisms are specific to that plant. They are able to survive for several years in the soil and in infected manures. Taubenhaus states that in Texas, a 3-year rotation on infected soil reduced the disease considerably; whereas, continuous watermelon culture soon results in such extensive and severe infection, that the crop is an absolute failure. The use of manure infected through the grazing of animals on diseased soil promotes the rapid spread of disease. Diseased plants become centers of infection for the whole field, because the wilt organisms may be distributed on the mouth parts of the cucumber beetle. Control of the beetle is important in limiting the spread of disease. Fulton and Winston (1914) showed that the fungus may be transmitted on the seed; hence, that seed disinfection (as described under anthracnose) is necessary (see below). Orton's Conquerer, developed on severely infested soil in South Carolina, has proved resistant to wilt in many sections, but in California, Oregon, and Illinois it has not proved very resistant. Possibly, different species of Fusarium cause the wilt occurring in these states.

Bacterial Wilt.—Watermelons are occasionally attacked by bacterial wilt, though, to this disease, they are the most resistant of all the cultivated cucurbits. Bacterial wilt was discussed in the chapter on melons.

Anthracnose.—The causal fungus is parasitic to all cucurbits, and watermelons are attacked very severely. The occurrence of the disease is closely correlated with rainfall during the growing season, being almost unknown in the West. It is especially destructive in wet seasons in the East.

The symptoms are black or brown spots, of irregular shape, on leaves, petioles, and stems. The dead areas spread rapidly under humid conditions, causing the plants to appear scorched. On the undersides of the fruit, near the soil spot, may be found raised, water-soaked lesions, which become lemon yellow, then change to black, sunken areas, which finally result in the collapse of the whole fruit. There is much loss through decay of infected fruit in shipment or at the market. Even apparently healthy fruit shipped during warm, humid weather often develop the disease during shipment. The fungus lives over winter on dead plants. It is also spread through infected manure, and seeds saved from diseased fruit carry the organism.

Control of the disease consists of a combination of crop rotation, seed treatment, and spraying or dusting with a fungicide. Seed is disinfected by soaking for 5 minutes in 0.1 per cent mercuric chloride, then rinsed in water and dried. According to Meier (1920), the disease is successfully controlled in Florida and Georgia by spraying with 4:4:50 Bordeaux, making applications every 10 to 14 days, from the time the vines begin

to run, until the crop is nearly matured. The habit of plant growth offers difficulties in the use of power sprayers, especially after the vines cover the surface. It is necessary to leave roadways for the sprayer by omitting every fifth row. Power sprayers with long booms make possible the spraying of several rows on each side of the roadway. Cardinall and Page (1922) found that applications of Cu compounds in dust form, either as dry Bordeaux or as dehydrated copper sulfate, gave better control than did the liquid-Bordeaux spray. Dusting equipment is cheaper, and roadways are not needed, if hand dusters are employed.

Stem End and Blossom End Rot (*Diplodia tubericola*).—The latter is a leathery decay of the distal end, affecting the fruit in the field According to Orton and Meier (1922), it seems to begin with an imperfect fruit, possibly due to defective pollination, which is later infected by decay-producing organisms, the fungus of stem end rot being most common, but other fungi also occur. Taubenhaus (1922) found that *Diplodia tubericola*, the cause of a sweet-potato-root decay, also produced stem end rot and blossom-end rot in watermelons. This fact indicates the advisability of separating sweet potatoes and watermelons by more than 1 year in the rotation. Imperfectly formed fruit, having become affected, serves as a source of infection both for stem and blossom end rot. Other workers have found various species of *Pythium*, a widely distributed soil-infecting fungus, to be also associated with blossom end rot.

Stem end rot is a decay starting at the basal end of the fruit. The *Diplodia* fungus occurs on decaying vegetation, and, as it is a very weak parasite, it is able to enter the melon only through wounds. Infection may occur in the field on the freshly cut stem at harvest time or through any injury to the rind. It may also occur during shipment, if the fungus is present in the straw bedding of the car or if infected melons are included in the shipment. Wounds caused by rough handling or by rubbing against the side of the car also allow the fungus to enter, but, since the cut stem is a wound present on all melons, the chances are greatest for the rot to start at that point. Orton and Meier (1922) describe an experiment in which the freshly cut stem of a fruit was inoculated with the fungus and stored at 24 to 32°C. In 42 hours, $\frac{3}{8}$ inch of the stem was softened. In 66 hours, the entire stem was softened. In 90 hours, $1\frac{1}{2}$ inches of the fruit was decayed. In 114 hours, the decay had advanced 4 inches from the stem. Thus, a healthy fruit becoming infected at picking time is rendered worthless in 5 days, less time than is ordinarily required to transport the melon to market. The main loss, therefore, occurs during transit. Of 1,012 cars inspected in 1921 by the Fruit and Vegetable Inspection Service of the U. S. Department of Agriculture, 68 per cent contained melons affected with stem end rot, and in these cars, from 7 to 10 per cent of the melons were decayed.

All varieties are about equally susceptible to the disease. The fruit may be attacked at any stage of development, so shiping immature fruit will not prevent loss. Stem end rot is prevented by keeping the spores of the causal fungus from entering or germinating upon the cut stem. This is done by clipping the stems and painting the freshly cut surface with a starch paste containing copper sulfate, at time of loading into the car. This paste should be used fresh. One quart is sufficient to treat a carload, so that cost is negligible. The paste consists of 8 ounces of starch and 8 ounces of copper sulfate dissolved in 1 gallon of hot water.

In picking melons for shipment, a stem about 2 inches long should be left on the fruit, so that it may be re-clipped to expose a fresh, healthy surface to the treatment at loading. This treatment cannot be used when melons are loaded with dead stems, as is sometimes the case toward the end of the shipping season.

Internal Browning.—Gilbert and Artschwager (1925) have described a disease in which brown, pithy, or corky areas are found as a peripheral ring about ¼ inch below the surface. The affected region is in the outer fruit flesh, just within the sclerenchyma sheath, where vascular tissue is abundant. The parenchyma cells bordering the vessels are killed. The trouble is attributed to lack of water during maturation and has been seen in Georgia and California.

Chemical Injury.—Since watermelons are often shipped in cars previously used for shipment of bulk chemicals, injury to the fruit during shipment may take place through contact with chemicals on the floor and walls of the car. Gilbert and Meier (1926) found that watermelons, when under pressure and in contact with moist acid phosphate, potassium chloride, sodium nitrate, and salt, were injured. Discoloration, pitting, and softening were common types of injury. The injury was slight when straw or building paper separated melons from chemicals.

Insect Pests

The principal insect pests are the spotted and striped cucumber beetles and the melon aphis, which were discussed in the chapter on melons.

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PART XII

COMPOSITAE

The composite family is one of the largest in the plant kingdom. In spite of this fact, only a comparatively few of the composites are of economic importance. Lettuce (*Lactuca sativa*) and globe artichoke (*Cynara scolymus*) are probably the two most important garden crops, while endive (*Cichorium endivia*), chicory (*Cichorium intybus*), and salsify (*Tragopogon porrifolius*) are grown to a much lesser extent.

CHAPTER XXIV

LACTUCA

Lettuce is grown throughout most of the temperate regions of the world and is, without question, our most popular salad crop. Within the last few years, there has been a great increase in its production and consumption in the United States. At one time, lettuce forcing was a very extensive industry. There has been a general decline, however, since the development of the winter-lettuce industry in the South and in California. Some lettuce is still being forced, chiefly in the thickly populated regions in the North and East. The education of the public by dieticians and medical men regarding the health-giving qualities of lettuce has no doubt been largely responsible for the great stimulus in consumption.

The various varieties of garden lettuce are closely related to the wild lettuce (*Lactuca scariola*). The latter is thought by many to be the ancestor of *L. sativa*, as the two species cross very readily.

History.—Sturtevant tells us that Europe and the Orient are the native homes of cultivated lettuce, which has been raised as a salad plant from the remotest antiquity. Sturtevant states that it appeared on the royal tables of the Persian kings about 550 B.C., that it was praised by Aristotle and described by Theophrastus. It is mentioned as present in China in the fifth century and as cultivated in England in 1340, on Isabela Island in 1494, in Hayti in 1565, and in Brazil in 1647. In 1828, Thorburn (America) offered 13 and in 1881, 23 kinds of lettuce for sale. In 1883 Vilmorin (France) described 113 kinds as distinct.

Plant Characteristics

Lettuce is an annual. Its leaves are alternate and arise from a short stem. The color of its leaves varies from light to dark green, which, in some varieties, may be partly or almost entirely masked by a reddish pigment, probably anthocyanin. The leaves vary from very narrow, as in asparagus lettuce, to almost circular in outline, as in most commercial varieties. The stem is at first very short but later, elongates and branches to form the paniculate inflorescence.

Inflorescence and Flower.—The inflorescence of the lettuce plant is a panicle. The flowers occur in heads. In the White Paris Cos variety, the number of florets to the head varies from 15 to 22. The receptacles are flat and naked. The involucre is cylindric, with several series of imbricated bracts. The outermost bracts are short. The flower is

perfect. The sympetalous corolla is yellowish, ligulate, truncate, and five-toothed at the apex. The five syngenesious stamens are attached to the corolla tube. The ovary is one-celled and develops into the achene. The style is single, and the stigma, two-lobed.

Floral Development.—Jones (1927) made a detailed study of flower and seed development. He found that when the stem of the lettuce plant is about 8 inches high, differentiation of the floral organs has usually begun. The oldest flower head terminates the main axis. The meristematic region of the receptacle is at first convex. It then becomes flattened and broadened, and following this, there arise simultaneously,

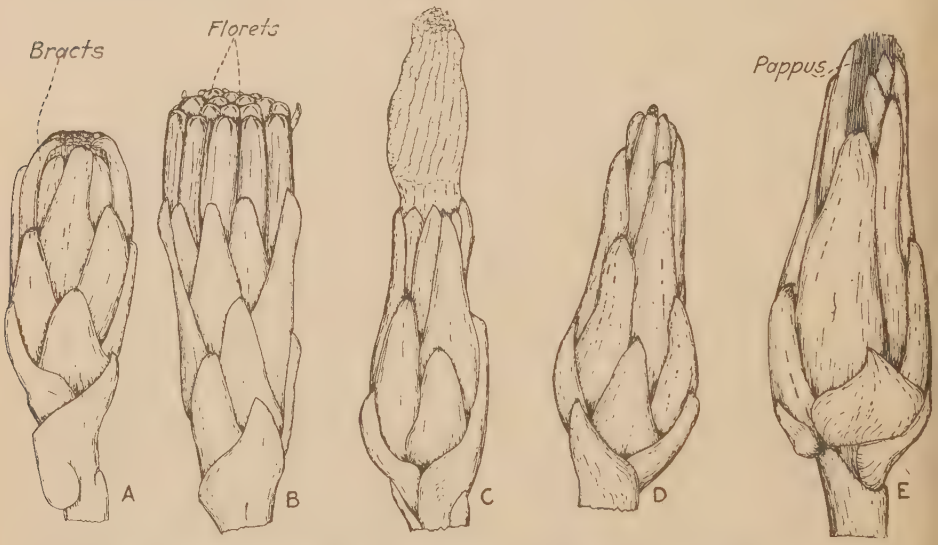

FIG. 87.—Flower and seed heads of lettuce. A. Twenty four hours before anthesis. B. Two hours before anthesis. C. Two days after anthesis, showing withered flower parts. D. After shedding of withered flower parts. F. Pappus appearing through the bracts.

over the entire surface, the protuberances which give rise to the individual flowers. The outline of the protuberances becomes angular, then a marginal ring of cells appears, which is the beginning of the corolla tube. The swellings which appear upon the inside of the corolla tube are the stamen primordia. An elevated meristematic ring of tissue near the base of the corolla tube and on its outer side gives rise to the pappus. Stamens and pappus appear almost simultaneously. The carpel is the last floral organ to be differentiated.

Oögenesis.—The megaspore mother cell is differentiated early in the life of the ovule. The four megaspores are formed with the haploid number of chromosomes by two successive divisions of the megaspore mother cell. The three micropylar megaspores soon degenerate, as a result of encroachment upon them by the functional innermost megaspore.

The enlarging megaspore is referred to as the embryo sac. The first nuclear division takes place near its middle. The daughter nuclei migrate toward opposite ends and, by two successive divisions, form four free nuclei at each end of the sac. The polar nuclei, one from each end of the sac, move toward the center and finally come to rest just above the egg in the mature embryo sac. They probably do not fuse until the time of fertilization. The egg and two synergids fill the micropylar end

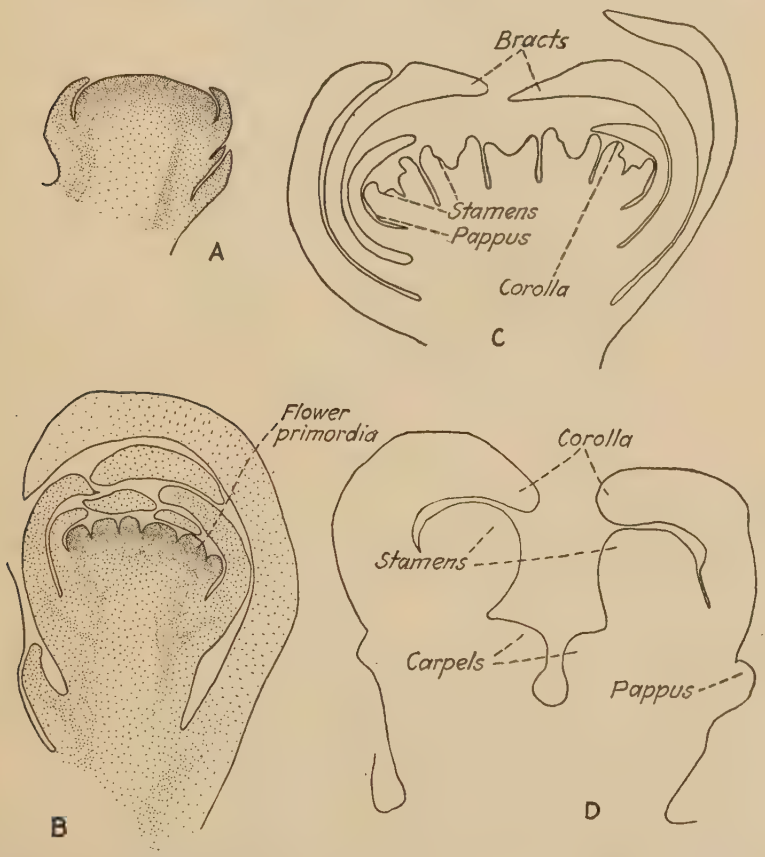

FIG. 88.—Development of floral organs of lettuce. A. Meristematic region from which the flowers arise. B. Primordia of the individual flower. C and D. Development of the floral organs.

of the embryo sac, while the three antipodal cells occupy a small neck at the opposite end. The egg is larger than its sister cells, the synergids. The nucleus is embedded in a deeply staining mass of cytoplasm at the summit of the egg.

Spermatogenesis.—A single row of hypodermal archesporial cells is differentiated very early in the life of the anther. Periclinal walls appear in these cells and cut off a single row of pollen mother cells on the

inside and an outer layer, which divides to form the tapetum, the middle layer, and the endothecium. The pollen mother cells and their nuclei enlarge considerably before the heterotypic division is initiated. Accord-

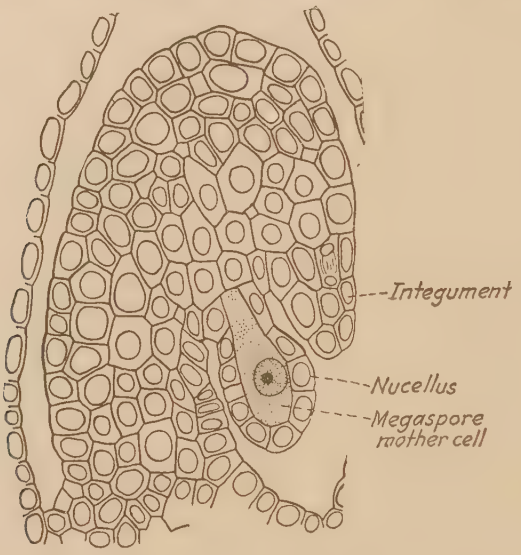

FIG. 89.—Ovule of lettuce.

ing to Gates and Rees (1921), cultivated lettuce has nine bivalent chromosomes. The reduction divisions are complete before the walls of the microspores are formed. The walls of all the microspores are formed

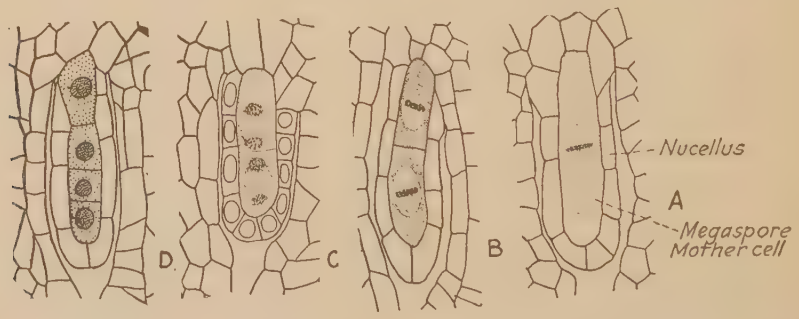

FIG. 90.—Formation of the megaspores in lettuce. A. Metaphase of megaspore mother cell. B. Metaphase of daughter cells. C. Telophase of daughter cells. D. Four megaspores.

simultaneously after the contents of the mother cell have been cut into four parts by invagination of the cytoplasm. When the mother-cell wall breaks down, the pollen grains escape, and the wall of the latter becomes remarkably thickened and sculptured. Several hours before

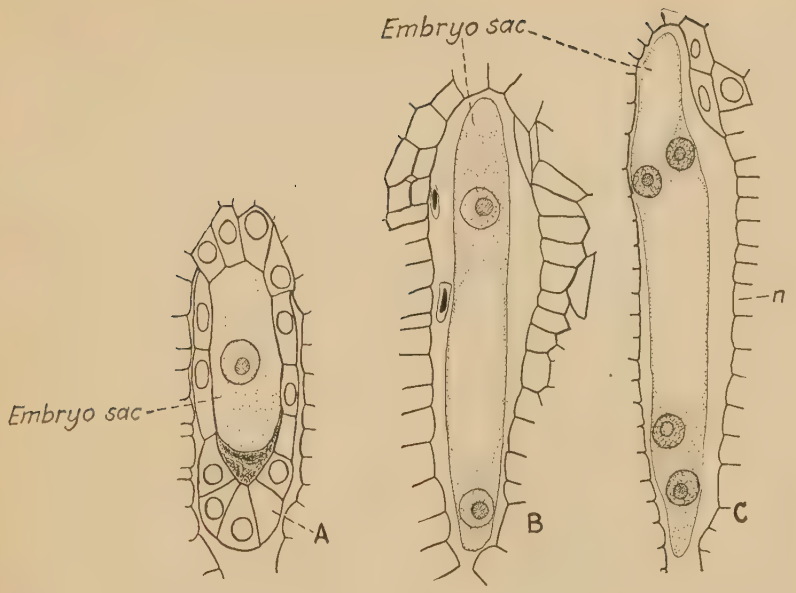

FIG. 91.—Developing embryo sac in lettuce. A. Enlarging embryo sac encroaching upon the other megaspores. B. Two-nucleate embryo sac. C. Four-nucleate embryo sac.

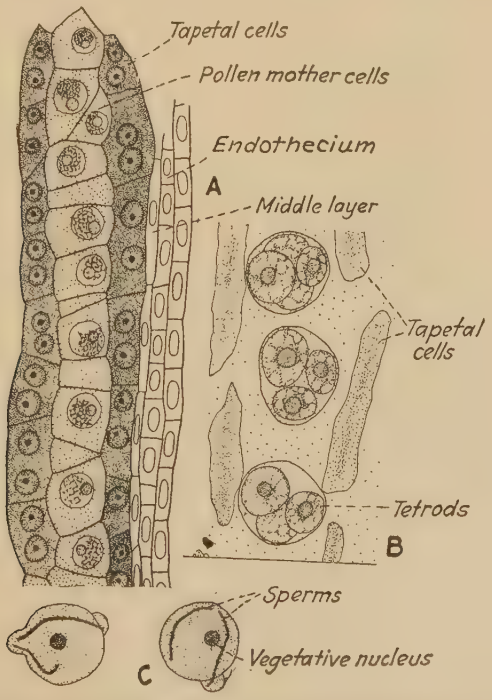

FIG. 92.—A. Longitudinal section through young anther of lettuce. B. Pollen tetrads. C. Pollen.

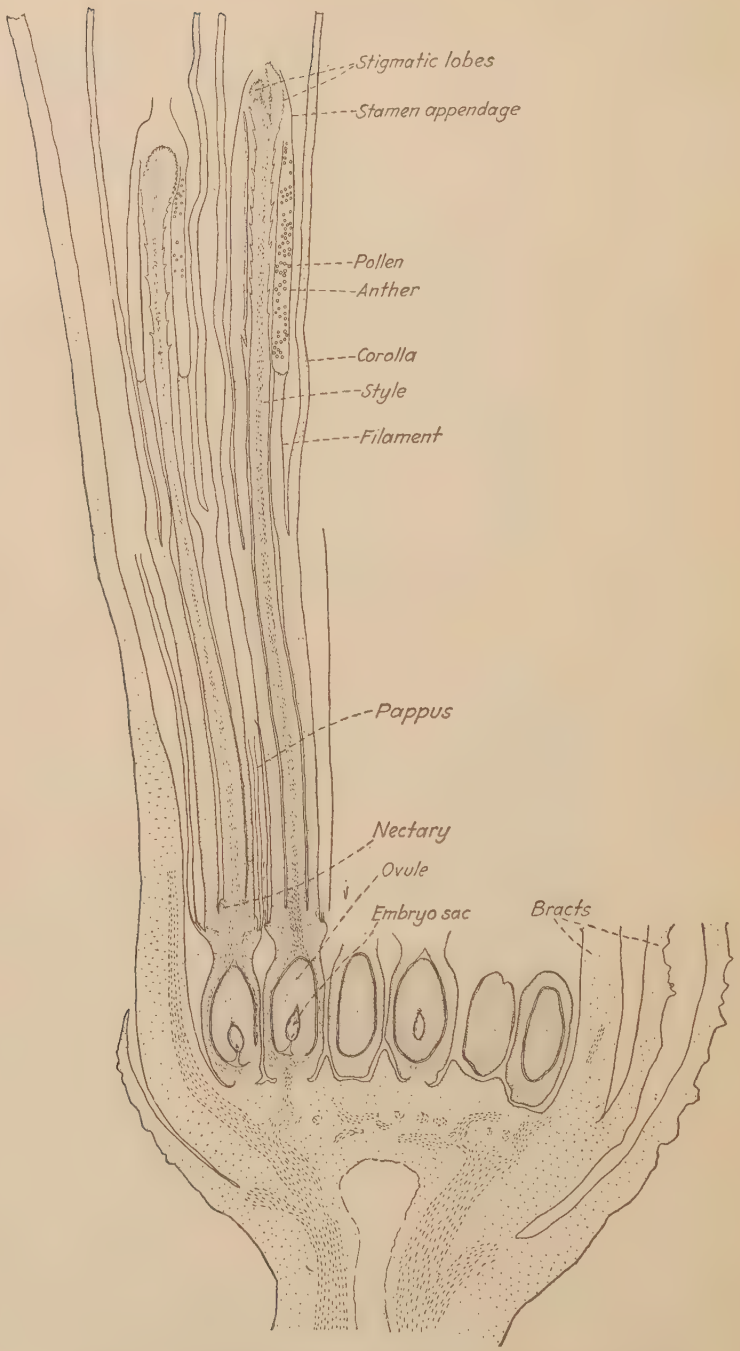

FIG. 93.—Longitudinal section of flower head at time of anthesis.

anthesis, the pollen grain contains two filamentous sperms and a vegetative nucleus. The sperms at this time reach almost halfway around the interior wall.

Anthesis.—The lettuce flower usually opens shortly after sunrise and remains open for an hour or two only. Then the corolla folds tightly together and does not open again. The lettuce plant has definite flowering cycles. Plants under observation at Davis, California, reached a flowering peak in the latter part of June and, another peak of less magnitude, in July. Flowering may continue on a single plant over a period of 2 months or longer. All the florets on a head open at the same time. Corollas, dehisced stamens, and withered styles and stigmas are shed in a cluster 2 or 3 days after anthesis of individual flower heads.

FIG. 94.—Floret of lettuce at time of anthesis.

Pollination.—The lettuce flower is almost entirely self-pollinated. The mechanism of pollination, however, is such that transfer of pollen from plant to plant is possible. At the beginning of anthesis, the pistil grows through the anther tube; at the same time, the brush hairs of the pistil sweep the pollen grains upward out of the pollen sacs of the dehisced anthers. According to Oliver (1910), the anthers dehisc before the flower head opens, and when the unexpanded stigmas appear through the staminal column, they are already covered with pollen. He asserts that when the stigmatic lobes expand, pollen falls on the papillae of the inner surface, insuring self-pollination. Knuth (1898), however, states that when the stigmatic lobes expand, they make a complete revolution backward and the stigmatic papillae come into contact with the pollen heald by the brush hairs of the pistil, thus bringing about self-pollination.

To check the observations of Oliver and Knuth, studies were made by Jones (1927) on methods of natural pollination in the White Paris Cos variety. A number of flowers were protected against insect visitation. When the stigmatic lobes were fully expanded, the number of pollen grains which had fallen upon their inner surface was counted. Seventy flowers were observed; of those, 58 did not have any pollen grains on their inner stigmatic surfaces. The number of pollen grains on the inner stigmatic surfaces of the other 12 flowers ranged from 1 to 7. The edges of the stigmatic lobes, however, are always covered with pollen, as are also the backs of the lobes. It was observed also that only occasionally do the stigmatic lobes make a complete revolution backward.

The number of pollen grains on the surface of the stigmatic lobes of flowers which were insect visited was also counted. Seventy flowers were observed. The number of pollen grains on the inner stigmatic lobes of

each flower ranged from 4 to 51. No doubt, some of this was foreign pollen. One plant had 169 flower heads open on June 26. During the short time that these flowers were open, 88 of the flower heads were visited by insects, and some heads were visited several times. On the same day, another plant had 82 flower heads open, and 60 of these were visited by insects. From these observations, it would appear that there is opportunity for cross-pollination. Pollination between plants may be much more frequent than has formerly been supposed.

Oliver suggests that crossing may occur if the pollen is washed from the stigmas by rain. Foreign pollen may then be brought in by insects. Rains occur very seldom, however, during the blooming season in the chief lettuce-seed-producing regions. The danger from this source is almost negligible. Even though the anthers dehisce and pollen grains are in contact with the stigma before the latter is extended through the staminal column, it is doubtful if any of the pollen tubes have penetrated the stylar tissue, because Oliver (1910) states he was able completely to depollinate the lettuce flowers by washing off the pollen with a fine stream of water from the fully extended pistils.

Lettuce flowers have a number of insect visitors. Knuth (1898) reports different species of flies' visiting the flowers. Flies were also observed visiting the lettuce flowers in various lettuce-seed fields, in California. At Davis, California, several species of small, short-tongued bees have frequently been noted gathering pollen from the flowers. To protect against insect visitation and the danger of introduction of foreign pollen, some seedsmen enclose the selected plants in cloth bags during the entire flowering period.

Fertilization.—In June, 1924, a study was made by Jones (1927) to determine the length of time between pollination and fertilization. The Iceberg variety was used. Pollination occurred about 8 a.m., and at 11 a.m., of the same morning sperms were observed in a few of the embryo sacs. By 1 p.m., or 5 hours after pollination, the majority of the embryo sacs contained sperms. In all samples taken at 2 p.m., stages of development from fertilized eggs to two-celled embryos were present. The time between pollination and fertilization in lettuce is then extremely short. From time of pollination, it was only 3 hours before the first fertilization stages were observed; and in less than 6 hours, fertilization had been completed in all the flowers studied.

Embryo Development.—The zygote divides shortly after fertilization. The first wall is transverse and cuts off a terminal cell, from which develop the cotyledons and epicotyledonary parts of the embryo, and a lower cell, which gives rise to the hypocotyledonary parts of the embryo. Both cells of the two-celled embryo divide at very nearly the same time, the upper usually slightly preceding the lower. The upper cell divides by a longitudinal wall, and the lower, by a transverse wall forming the

four-celled embryo. Every cell of the four-celled embryo, by division, contributes to the formation of the eight-celled embryo. In like manner, the 16-celled embryo is formed by the division of each cell of the eight-celled embryo. In the 16-celled embryo there are five tiers of cells. The

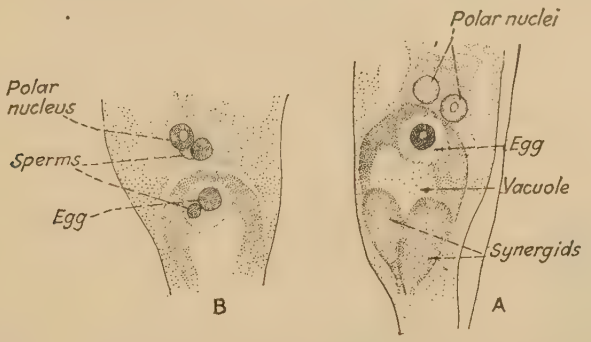

FIG. 95.—A. Mature embryo sac of lettuce. B. Fertilization.

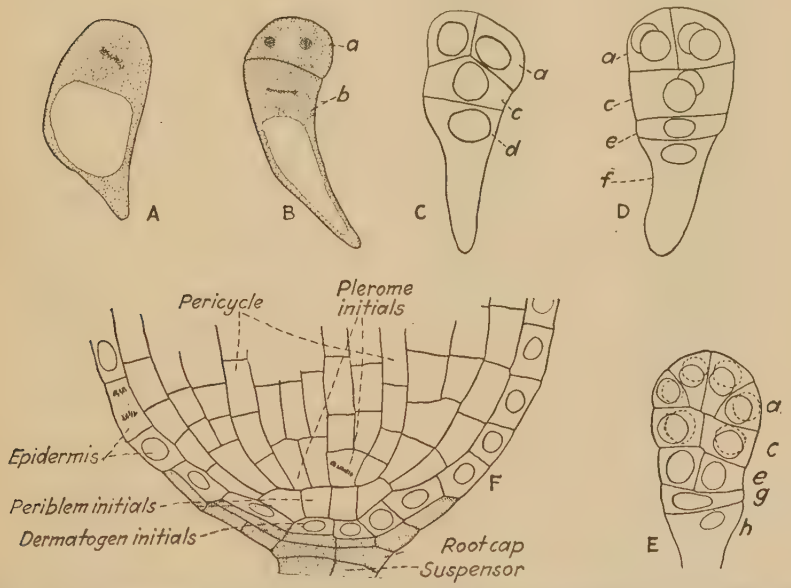

FIG. 96.—Developing embryo of lettuce. A. Zygote in metaphase. B. Two-celled embryo. Cell a in telophase and cell b in metaphase. C. Four-celled embryo, c and d have been derived from b. D. Eight-celled embryo, c, e, and f have been derived from cell b of the 2-celled embryo. E. Sixteen-celled embryo. F. Lower portion of embryo showing origin of the various tissues.

upper tier of eight cells, which has been derived from the upper cell of the two-celled embryo, contributes the cotyledons and plumule. The second tier of four cells gives rise to all the primary tissues of the hypocotyl and the plerome initials. The third tier of two cells produces dermatogen

cells and periblem initials. The fourth tier (one-celled) contributes the dermatogen initials and a portion of the root cap. Cells of the root cap are formed by periclinal division of the cells of the dermatogen. The fifth tier (one-celled) develops into the filamentous suspensor.

The embryo reaches its maximum development and the achene ripens within 11 to 13 days after anthesis, depending upon climatic conditions.

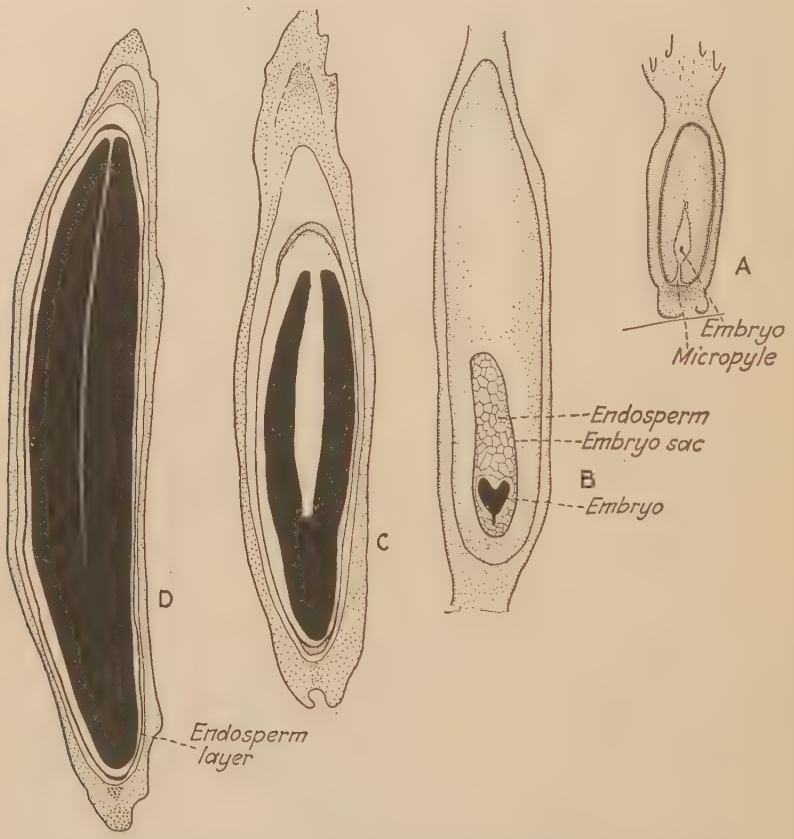

FIG. 97.—Development of the lettuce achene. Embryo is colored black.

Endosperm.—Divisions of the endosperm nuclei are at first slightly in advance of those of the embryo. Free nuclear division takes place for a time, but at about the time the young embryo is eight-celled, walls appear in the endosperm. At this time, the endosperm cells completely fill the embryo sac; they are few in number, very large, and highly vacuolate. The endosperm cells grow sufficiently rapidly for a time to occupy the space within the rapidly enlarging embryo sac. The developing embryo encroaches upon the endosperm, digesting and absorbing it. By the seventh day after pollination, the endosperm tissue is almost entirely

destroyed. The walls of the two outer cell layers of the endosperm become somewhat thickened and are very consp cuous during the late stages of development. This membrane persists in the ripe seed and completely invests the embryo. The endosperm cells do not contain much reserve food at any stage of their development. When the seed is ripe, all of the reserve food is stored within the cells of the embryo, and it is upon this food supply that the seedling must depend, until it starts to manufacture its own food.

Soil and Climatic Relationships

Soils.—Lettuce is grown successfully on a wide range of soil types, from clay loams to sandy loams and muck, but it attains its highest quality on fertile-loam soils. Where the crop is subject to high temperatures during the early part of the growing season or where it matures during hot weather, heavier types of soil should be used, as they retain moisture better and are somewhat cooler. Lighter soils should be used to produce the crop which grows and matures during the cool season of the year. Clay soils, though difficult to work, yield excellent crops.

Climatic Requirements.—Lettuce of high quality can be produced only where the temperature of the soil and air is moderately cool. This requirement must be kept in mind, especially by those who are attempting to grow lettuce during the summer months. Fluctuating high and low temperatures are not conducive to good growth. High temperatures favor the rapid elongation of flower stalks, cause a bitter flavor to develop. produce loose heads, and accelerate the development of lettuce diseases, During the early stages of development, lettuce will tolerate a considerable amount of frost, but, if severely frosted when mature or nearly mature, it is more subject to disease both in the field and in transit. Generally, frosted lettuce needs close trimming and is therefore not attractive. The maturing plants make very little growth during continued frosty weather, and, although they become solid, they remain small, their leaf tips are injured, and they bring a comparatively low price.

Light Relations.—Gourley and Nightingale (1921) grew a loose-leaf variety of lettuce in shade (under cloth) and also in sunlight.

> After about three weeks' growth the plants in both plots were ready for market. The plants in diffuse light had approximately twice the total leaf area of those in the open. The leaves of the former plants were very smooth, extremely thin and tender, and easily broken. Flowers were not produced on the shade plants until 35 days after they appeared on the open plant, and the flowers on the former were few and many were abortive.

In the shade, the temperature of the air usually ran a few degrees higher than in the open, while the temperature of the soil was slightly

lower. No doubt, the difference in temperature of the two lots had some effect in the type of growth produced.

Hendricks and Harvey (1924) were able to mature lettuce plants and bring them into flower and seed by use of artificial light only. A temperature of 25°C. was used, and a light intensity of 900- to 1,350-foot candles.

Culture

Growing Lettuce under Non-irrigated Conditions.—Where lettuce is grown without irrigation, seeding is usually done on the level. As a rule, rows are planted 12 to 15 inches apart, and the plants are thinned before they start to crowd to 10 or 12 inches apart in the row, depending upon the variety.

Transplanting.—The transplanting method is used only where small acreages are planted and especially when an early crop is desired for local markets. Seed is sown in hotbeds or cold frames about a month before the plants are to be used for transplanting. It may be sown in rows or broadcast in the plant beds. At time of transplanting, the plants should be 2 to 3 inches high, stocky, and well hardened. They should be set above the level of the soil. The dibble is the tool most generally used in transplanting.

Growing Lettuce under Irrigation.—Where the lettuce crop is grown under irrigation, planting is usually in double rows on raised beds. It is essential to have the land level and the beds of a uniform height, so that water may be applied without flooding certain areas and leaving others dry.

In general, the soil should be plowed and then disked and harrowed to a fine, mellow condition before the seed beds are made. It is difficult to make good beds or do good seeding on a cloddy soil. When seeding is done during very hot weather, however, aeration is facilitated and better stands are obtained, if the soil is left a little crumbly.

In California, the general custom is to grow two rows on a bed with furrows between the beds to carry the irrigation water. In some Western states, the planting of single rows on raised beds is practiced. Usually, a larger yield is produced where two rows are grown on a bed. The one-row bed, however, requires somewhat less expense for cultivation. The bed-and-furrow system facilitates irrigation and drainage and gives good aeration about the plants.

Width of bed, distance between beds, and depth of furrow vary in different regions, according to the climatic conditions and type of soil. Width of beds varies from 18 to 20 inches or more and width of furrows, from 18 to 22 inches or more. It is seldom that the beds are less than 3 feet from center to center, and usually they are farther apart than this. They should be 4 to 10 inches high after smoothing. In regions where strong

desiccating winds are prevalent, and on light, sandy soils, low beds are to be preferred, as they expose less surface and retain moisture better.

A disk, turning plow, single or double lister, or two-row cultivator equipped with large shovels may be used to make the beds, or ridges. Double or triple listers pulled with a tractor are often used. The ridges are often made and smoothed off and the seed, planted in one operation.

Seed is usually sown by attaching two planters to the sled which shapes the bed. This system saves time, and, furthermore, the two rows of lettuce on a bed are exactly the same distance apart throughout their length, a fact which makes cultivation easier.

Lettuce seed is very small and should be sown as shallow as possible, but it must be covered with sufficient soil to insure germination. Thick seeding is objectionable, as it increases the cost of thinning and involves waste of seed. From 1 to 1½ pounds of seed to the acre is sufficient, if the soil temperature and moisture conditions are favorable.

The distance between rows should not be less than 10 inches. For the variety New York, some growers space the rows from 15 to 17 inches apart, to give room for the development of the large heads. Where rows are too close on top of the bed, cultivation is more difficult and expensive, various diseases are likely to develop, and mature heads are usually smaller.

Where large acreages are grown, successive sowings should be made at intervals of 10 to 14 days throughout the lettuce-planting season. This extends the marketing of the crop over a longer period and gives a more uniform distribution of labor in both packing house and field.

Germination.—Davis (1924) found that the amount of water absorbed by lettuce seed must be about 75 to 80 per cent of its air-dry weight if the best germination is to be obtained. There must be an abundant supply of O_2 in the soil around the seed. An attempt should always be made to plant the seed as shallow as possible, because of the more liberal supply of air near the surface. On heavy, poorly aerated soils, it is more important to plant shallow than it is on light soils. According to Davis (1924), there is a very close relation between the supply of air to the seed and the temperature at which it will germinate. The layers of tissue surrounding the embryo in some way retard O_2 absorption. The O_2 supply to the embryo is more retarded at high than at low temperatures. The higher the temperature, therefore, the greater must be the O_2 supply to the seed, in order to obtain germination. At 30°C., usually no germination takes place, but the embryos will grow if the seed coat and endosperm layers are removed. This indicates that lack of O_2 is the principal factor causing delayed germination. As a rule, the oxygen-temperature relations are much more marked in freshly harvested than in aged seed. Two-year old seed may and often does give more rapid and uniform germination under field conditions. Kotowski (1926) planted lettuce seed of the

New York variety 2 centimeters deep in quartz sand at temperatures ranging from 4 to 30°C. As shown in Table 80, good germination was obtained at all temperatures used, except 30°C.

TABLE 80.—GERMINATION OF LETTUCE SEED AT DIFFERENT TEMPERATURES (*Kotowski*, 1926)

Temperature, °C	4	8	11	18	25	30
First seedling, days after sowing	29	14	8	4	3	0
Last seedling, days after sowing	45	24	15	6	6	0
Seedlings in per cent of seed sown	86	87	91	87	98	0

Size of Seed.—Cummings (1914) found that seedling-lettuce plants grown from large seed are higher and have longer and broader leaves than seedling plants of the same age from small seed. The large seed produced heads of larger size, and the percentage of marketable heads was higher. Varieties under observation were Hittinger's Belmont Forcing, Boston Forcing, Hanson, Deacon, and Iceberg.

Irrigation.—When furrow irrigating, the water should be allowed time to "sub" through the beds. Irrigating the beds immediately after planting is usually preferred when the weather is warm and dry. The water is often kept running in small streams down the furrows until the plants are up. This cools the soil and produces a higher percentage of germination. In cool weather, such heavy irrigation immediately after planting is not necessary. In heavy, clay soils, deep furrows are used with a small head of water. If the water comes up close to the top of the bed, the soil will bake and crack when it dries, and the seedlings will come through.

Methods of irrigating the growing crop vary considerably in different localities and at different times of the year. If too much water is applied when the heads are maturing, the latter are liable to be soft and loose. Less water is required when the weather is cool and humid than when it is hot, dry, and windy. More frequent irrigations are needed on light, sandy soils than on those types which are more retentive of moisture. It takes some experience to know just when lettuce needs water, but, in general, the plants are suffering when they take on a dark-green color and the leaves feel tough and leathery.

Thinning and Hoeing.—Lettuce should be thinned before the plants start to crowd. In warm weather, this may be 3 weeks after planting; but in cool weather, it may be 8 weeks. The plants are blocked out 12 to 15 inches apart in the row, by use of special, short-handled hoes, and, at the same time, thinned by hand to one in a place. Plants not true to type are also removed at this time. Thinning is a very important operation, and in many cases when it is done under contract, a part of the money is withheld until the work is completed satisfactorily.

Harvesting.—It is usually necessary to make several cuttings, in order to obtain all of the heads at the best stage of maturity. When the weather is cool, mature lettuce may remain in the field for a long time without bursting. In very warm weather or when freezes are expected, the heads are harvested as soon as they are mature. The stem is cut at the ground level or just below he surface. Most of the trimming is done at the packing shed. Lettuce heads in which the seed stems have started to elongate, which have burst, have tip-burn, or are diseased are discarded in the field.

Marketing

Grading and Standardization.—Much of the success of the lettuce industry in the West has been due to the rigid grading and high standardization of the product. Most of the shippers have voluntarily adopted the federal grades. The detailed specifications for the federal grades are subject to slight modifications and therefore are not included here. They may be obtained from the U. S. Department of Agriculture, Washington, District of Columbia.

U. S. Fancy Grade consists of heads of lettuce which are of similar varietal characteristics and are fresh, well trimmed, and solid. They must not be decayed, split, or burst. They must be free from seed stems, doubles, and damage caused by freezing, dirt, wilting, tip-burn, diseases, insects, and mechanical or other means.

U. S. Grade No. 1 contains the same specifications as those outlined for U. S. Fancy Grade, except that, in this one, the heads need to be only "reasonably solid" instead of "solid."

U. S. Grade No. 2 has no specifications regarding solidity, trimming, splitting, doubles, or damage caused by dirt. The heads must be free from "serious" freezing damage. Otherwise, the requirements are the same as for U. S. Grade No. 1.

Packing for Shipment.—In some sections, lettuce is packed in the field, but the demand for a standardized pack is making centralized packing more and more popular. At the packing shed, a few of the outer leaves are trimmed off, and the small or loose heads, culled out. A sufficient number of wrapper leaves are left on to protect the head. When trimmed, the heads are packed in crates.

The large lettuce crate used in the West is lined with two strips of heavy waterproof paper, which cover the bottom, sides, and ends and fold over the top to protect the contents and keep the lettuce cool and fresh. Three layers of heads are packed tight in the crate, with stems up, generally with cracked ice between the layers. Usually 30 pounds or less of ice is used in each crate. The crates are placed in the refrigerator car as soon as packed. From 4,500 to 7,500 pounds of ice, depending upon the temperature, is usually placed on top of the crates in the car instead of

in the bunkers. A slight bulge is given the crate, so that the heads will not move about in the container. The usual carload is 320 standard crates.

When packing in hampers, the bottom heads are placed with the stems down and the second layer, with the stems up, thus alternating each succeeding layer. The top layer, however, is always packed with the stems up. When loading hampers in the car, they are usually stood on end, with alternate hampers reversed. Succeeding layers are placed in the same way, with tops against tops and bottoms against bottoms.

Ramsey and Markell (1917) have shown that in regions where lettuce drop (*Sclerotinia libertiana*) is prevalent, there is usually considerable loss during transit unless the heads are carefully trimmed and pre-cooled. When the lower diseased leaves were removed and the crates of lettuce precooled to about 4°C. at the shipping point, there was considerably less decay in transit than when these precautions were not taken.

Consumption.—Wellman (1926) estimated that the yearly per capita consumption of head lettuce in the United States increased from less than one head in 1917 to five in 1925, an increase of 525 per cent. The per capita consumption is somewhat greater than the data show, because only the carlot shipments could be taken into consideration.

The chief cause for this low consumption is to be found in the fact that many people do not eat head lettuce at all, and many others eat it only occasionally, mainly because they can not purchase it readily throughout the year. In the large cities in which lettuce is available most of the time, the per capita consumption is from two to three times that for the United States as a whole. Just how much the total consumption can be increased by the further development of the small markets is uncertain.

Lettuce shippers, particularly in the Western states, have already made considerable progress in developing the smaller markets by shipping lettuce in mixed cars. A market which is not able to handle a straight car of lettuce can often handle a car containing a number of vegetables.

Shipping Season.—Aside from the greenhouse crop in the North, commercial lettuce is mainly of two varieties—Big Boston and New York. The latter is produced exclusively in the West; the former, in the East and South. Arizona ships a considerable amount during the months of December, January, and April. Washington ships some lettuce from May to November, but the bulk of the crop is shipped during May and June. Colorado ships most of its crop during August and September; and Idaho, during October and November. All of these states ship the New York variety. New York ships a large quantity of Big Boston from July to October inclusive, with the peak during July and August. North and South Carolina have a rather short shipping season, most of the crop moving during the month of May. Table 81 gives the carlot ship-

ments of lettuce by months for the entire United States for the years 1917 to 1926 inclusive.

TABLE 81.—CARLOT SHIPMENTS OF LETTUCE FOR UNITED STATES BY MONTHS, 1918–1926

Years	January	February	March	April	May	June	July	August	September	October	November	December	Total
1917	364	212	344	705	674	145	522	436	322	273	466	965	5,428
1918	957	1,124	1,167	725	499	92	382	560	383	123	319	628	6,959
1919	767	717	829	1,090	831	181	395	695	653	358	565	937	8,018
1920	2,023	1,621	1,353	1,063	1,172	365	980	934	832	596	1,388	1,191	13,818
1921	2,356	1,984	2,219	1,974	1,067	670	1,399	1,140	1,302	1,253	1,481	1,771	18,616
1922	2,245	1,919	2,584	3,167	1,859	801	1,536	1,787	1,303	1,503	1,453	2,083	22,240
1923	3,119	2,736	4,099	2,520	2,015	1,310	2,232	2,493	2,493	1,839	2,048	2,285	29,485
1924	3,807	3,626	2,789	2,885	3,087	1,261	1,715	2,053	2,053	1,821	2,145	2,762	30,791
1925	3,309	3,378	4,987	4,006	2,900	1,526	2,499	3,269	2,962	2,765	2,380	3,325	37,306
1926[1]	4,253	3,559	4,018	4,135	3,832	2,519	2,705	2,860	3,283	3,576	2,920	4,300	41,960

[1] Subject to revision.

TABLE 82.—SHIPPING SEASONS AND CARLOT SHIPMENTS OF HEAD LETTUCE BY STATES OF ORIGIN, 1920–1926

State	Shipping season	1920	1921	1922	1923	1924	1925	1926[1]
Arizona	November to May	254	168	678	1,108	2,049	3,519	4,840
California	All year	7,358	9,850	9,744	15,113	18,480	21,619	27,401
Colorado	June to November	129	234	812	1,436	1,036	3,096	2,773
Florida	November to April	2,940	2,267	3,310	3,146	2,257	1,519	902
Georgia	February to April	.....	.....	5	5	3	26	38
Idaho	May to December	25	180	889	1,241	532	501	381
Louisiana	November to April	7	1	14	3	8	6	4
Michigan	June to November	110	100	81	208	55	7	
Minnesota	July to October	56	44	85	53	36	12	
Missouri	May to September	.....	.....	.....	.....	.....	14	12
Nevada	November to December	.....	.....	.....	.....	.....	12	15
New Jersey	April to June, September	208	469	571	456	417	463	296
New Mexico	August to October	.....	.....	.....	11	95	74	121
New York	June to October	1,775	3,240	3,167	3,817	3,698	3,819	3,015
North Carolina	March to May	207	445	622	718	714	537	540
Ohio	November to June	16	27	33	44	94	81	46
Oregon	January to November	3	25	129	168	127	60	46
Pennsylvania	June to September	23	36	34	22	17	18	36
South Carolina	March to May	121	716	987	577	423	736	372
Texas	December to March	139	132	113	102	85	119	122
Utah	October to November	.....	5	15	31	7	9	3
Virginia	April to May, October to December	55	154	119	70	110	102	70
Washington	May to November	354	635	812	1,081	674	820	898
Wyoming	August to October	.....	.....	11	74	16	26	15
Total United States		13,788	18,738	22,240	29,485	30,935	37,206	41,960

[1] Subject to revision.

The principal shipping season for California lettuce is during the late fall, winter, and early spring. Most of the lettuce from the Imperial Valley moves during late December, January, February, March, and early April. The Los Angeles district ships the greater portion of its crop in fall and spring, before and after the movement of lettuce from Imperial Valley. The development of districts along the coast in Ventura, Santa Barbara, Santa Cruz, Monterey, and other counties has made possible the shipment of lettuce throughout the summer. The shipping seasons for the various states and the carlot shipments for the years 1920 to 1926 are given in Table 82.

Classification

Tracy (1904) has classified the lettuce varieties into three large groups: (1) butter, (2) crisp, and (3) cos. The butter varieties have a buttery flavor, and the leaves are soft and pliable in texture. Crisp varieties are coarser veined, larger ribbed and more brittle than butter varieties. Cos varieties are more upright in their habit of growth than are those of the former two groups; the heads are long, with spatulate-shaped leaves. Tracy classifies the lettuce varieties as follows:

Butter Varieties:

Cabbage heading.

Plants wholly green. Mammoth Black-seeded Butter, Hubbard's Market, Deacon, Unrivalled.

Plants tinged brownish, larger part green. Big Boston, California Cream Butter.

Plants brownish, small portion, only, greenish. Brown Head, Eureka.

Bunching.

Plants wholly green. Earliest of All.

Plants brownish. Hero.

Crisp Varieties:

Cabbage heading.

Plants wholly green. New York, Denver Market, Hanson, Malta.

Plants tinged brownish, large part greenish. Iceberg.

Plants brownish, small part only greenish. Mignonette, Sugar Loaf.

Bunching.

Plants wholly green. Black-seeded Simpson, White-seeded Simpson, Grand Rapids.

Plants brownish, small part only greenish. Prize Head.

Cos Varieties:

Spatulate leaved.

Self-Closing.

Plants wholly green. Paris White Cos, Dwarf White Heart Cos.

Plants brownish. Red Winter Cos.

Loose closing, Bath Cos.
Lanceolate-leaved varieties. Asparagus.
Lobed-leaved varieties. Asparagus Lobe-leaved.

Varieties

While there are a hundred or more varieties of lettuce listed in American seed catalogs, only a few of these are used in America in any quantity. The most important ones are as follows: New York, Big Boston, Grand Rapids, Salamander; Prizehead, Hanson, Paris White Cos, Early-curled, or White-seeded Simpson, Prize Head, May King, Black-seeded Tennis Ball, and Iceberg.

New York (Los Angeles, Los Angeles Market, Wonderful, New York Special, and Mountain Iceberg).—According to Morse (1923), the New York is known in Europe as *Chou de Naples*, or Neapolitan Cabbage. It is almost the only variety grown in the West. Shippers and buyers refer to it as Iceberg. The variety which the seedsmen know as Iceberg, however, has the edges of the leaves tinged reddish brown. The leaves are broad, fairly blistered and crumpled, and heavy veined, the margins are serrate, and the borders, frilled. The variety New York is entirely free of pigment, crisp, and dark green; and when mature, the head is large, hard, and of a slightly flattened globe shape. Some strains of New York have slightly elongated heads. These are not so easy to pack in the crate as those which are slightly flattened and are not so well received on the market. The seeds are whitish.

Big Boston.—Big Boston is the principal variety grown in the East and South for shipment. This variety is of the butter type and forms a medium-large globe-shaped head. The leaves are broad, mostly smooth, and light green, and the outer ones are turned backward near the borders and have a slight tinge of brown on the margins. The seeds are whitish.

Black-seeded Simpson.—This is a crisp, non-heading variety; the plant grows to a large size and is fairly compact, with the innermost heart leaves curving inward. The leaves are broad, much blistered, crumpled, and twisted, thick, coarse, with midribs protruding, margins serrate, and borders excessively frilled. The color is pure light green. The leaf is rather sweet in taste and coarse in texture. The seeds are blackish. It is the most popular variety for the home garden, and it is grown also to a considerable extent in the market gardens of the North. It is popular as a home-garden variety, because it does well under rather adverse conditions and is very easily grown.

Lettuce Breeding

Most of the improvements in our present-day varieties of lettuce have been brought about by selection of outstanding individual plants.

The lettuce plant is almost entirely self-fertilized, and most plants are, therefore, in a fairly homozygous condition. Many strains of the commercial varieties on the market today are the progeny of selected individual plants. A few of the best plants are staked when they are in their prime for market. Muslin bags are placed over them when flowering begins, to prevent the introduction of foreign pollen by insects. The covering is usually left on the plants until they are harvested. The seed from the different plants is planted in separate rows side by side the following year for comparison, and only a few outstanding strains are kept for increase. The following year, perhaps, only one or two of the strains will be retained for multiplication. The best strains are increased from year to year, until sufficient seed is obtained to plant the contract fields.

Crossing between certain varieties is also a potential method of developing better varieties. When making lettuce crosses, the general method of procedure is that developed by Oliver (1910). When the flower is open and the style is fully extended, depollination is accomplished by use of a fine stream of water. Pollen is then introduced by brushing the stigmatic lobes with a flower head of the paternal parent.

When Durst (1915) crossed Big Boston (heading type) with Grand Rapids (non-heading), the F_1 was found to be intermediate in heading habit. In the F_2 a graduation in heading habit was secured, which extended from one parental type to the other. In the F_3 generation, some families bred true, while others produced a mixed population. The heading habit in lettuce is apparently inherited according to the theory of multiple factors.

Seed Production

A large portion of the lettuce seed of all American varieties produced in the United States is grown in California. Here, almost all varieties for seed production are sown during December, January, or February. Black adobe and sedimentary soils are excellent for lettuce-seed crop. Planting is the same as for the market crop, except that rows are spaced about 20 inches apart, generally planted on the level, and the plants are thinned to 8 to 10 inches apart. In varieties with overlapping head leaves, such as New York, Iceberg, Hanson, and Mignonette, the heads are quartered or removed in order to allow the seed stem to develop normally. This operation must be done before the head becomes hard and the seed stem starts to elongate. If done too soon, many varieties will continue to head; and if delayed too long, there is danger of injuring the seed stem. Varieties like Big Boston, Tennis Ball, and Unrivalled are often just skinned, *i.e.*, the outer leaves are removed to allow the inner leaves to loosen and the seed stem to come through. In the non-heading types of lettuce, such as Black-seeded Simpson and Grand

Rapids, there are no incurving leaves to inhibit the development of the seed stem. When the spring is very wet, almost all varieties have the basal leaves stripped off, to provide aeration about the stem and prevent rot.

Rogueing is one of the most important operations in the production of lettuce seed. The highly bred varieties, like New York, are usually rogued two to three times; other varieties, at least once. Stock-seed fields are rogued from four to six times.

The lettuce plant blooms over a considerable period of time. Seeds of any one head are usually ripe within 11 to 13 days after flowering. It requires an expert to determine the proper time to harvest in order to

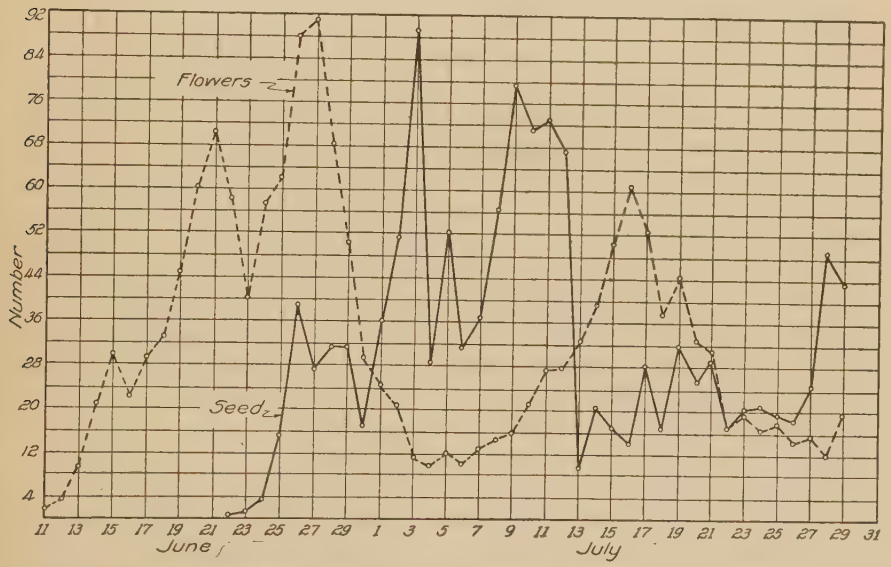

FIG. 98.—Flowering and seed ripening curve of lettuce. Average of nine plants. Variety Iceberg. (*Davis, California.*)

get the maximum amount of seed. If cut too soon, the yield will be low. If the plant is allowed to stand in the field too long, a considerable amount of seed may be lost by shattering. Some varieties shatter more than others. Some, such as Big Boston and Unrivalled, do not shatter at all. This is one of the weaknesses of New York, from the standpoint of the seed producer. Grand Rapids and Black-seeded Simpson also shatter badly. If seed plants are left standing too long, the seeds sunburn and change color somewhat.

Harvesting is usually done in the morning, while the plants are damp. They are cut off near the ground with a sickle, and, if not too damp, they are hauled to large canvas sheets immediately and stood upright on

these to dry. If very damp at time of cutting, they are usually hauled to the sheets in the afternoon.

The seed is usually rolled out with a heavy, wooden roller. The rolling should be done in the morning before the plants are too dry. This is especially necessary with the black-seeded varieties, to prevent the stems from breaking. It is very difficult to remove the small stems in cleaning, and the appearance of the seed is spoiled. Coarse stems are raked off, and much of the remaining coarse material is removed by screening. Seed and chaff are then bagged and hauled to the cleaning house, where they are run, by gravity, through a series of screens and fanning machines, to take out the chaff and light seeds. The lettuce seed is then bagged and stored, until ready to be shipped.

Diseases

Downey Mildew (*Bremia lactucae*).—It attacks lettuce both in the greenhouse and out of doors, in this country and in Europe. First indications of the disease appear as light-green or yellowish areas on the upper surface of the leaf. On the underside of these discolored areas appears a downy white growth of mold. Conidia appear at the same time. The spots, which vary from ½ to ¾ inch in diameter, may coalesce and become brown. Milbrath (1923) has shown that the variety New York is very susceptible to mildew attack but that Iceberg, Big Boston, and Hanson show considerable resistance. In the large lettuce-growing districts of the West, the latter three varieties are not grown for shipment, and downy mildew will need to be combatted mainly by selecting for resistance within the New York variety. Mildew is most abundant during the rainy season. Erwin (1921) gives the following recommendations for its control in greenhouses: (1) Destroy wild-lettuce plants near the greenhouse, for these act as summer hosts for the mildew; (2) give a 4:4:50 application of Bordeaux as soon as the plants are up, a second at time of "pricking off," and a third spraying before the plants go into the permanent bed; (3) sub-irrigate if possible, especially during periods of cloudy weather, thereby keeping the foliage dry; (4) ventilate well but prevent sudden changes in temperature.

Slimy Soft Rot, or Slime.—Slime is a disease caused chiefly by the fungus *Botrytis*, although a number of bacteria have been found associated with it. The disease appears in the field, in transit, and in storage and is characterized by a slimy, slippery condition of the affected parts and a very offensive odor. Tissues of lettuce are predisposed to slime by the bruising of leaves during handling and by frost injury, tip-burn, and sun scald. In the field, the control of slime usually resolves itself into the prevention of tip-burn. In transit, slime may be kept in check by packing only healthy and uninjured heads and by shipping under dry, cool

conditions. It is impossible to keep the heads dry, however, with our present methods of handling.

Lettuce Drop (*Sclerotinia libertiana*).—This causes considerable loss in the East and South. Burger (1913), working at the Florida Agricultural Experiment Station, states that the first symptom of the disease is the wilting and dropping of the lower leaves. Later, the head becomes affected and falls over. The entire plant is soft and watery and looks as if it had been scalded. The fungus mycelia appear as white cottony masses on the underside of each infected leaf. Later, black sclerotia are formed from these masses of mycelia. The sclerotia are able to persist for some time in the soil under adverse conditions. In time, they give rise to small, mushroom-like, fruiting bodies, the apothecia. These are about ¼ inch in diameter and are borne at the summit of a short stalk. Within these apothecia, are the asci, which contain the ascospores.

An effective method of control in the field is crop rotation. Celery should not be used in the rotation, as it is also a host to this fungus. In the greenhouse, the disease can be controlled by soil sterilization.

Jagger (1920) found that *Sclerotinia minor* produced a diseased condition in lettuce almost identical to that caused by *S. libertiana.*

Brown Blight.—Brown-blight disease is caused by an unknown soil fungus. It has caused considerable loss to the lettuce growers of Imperial Valley and occurs in other sections of California and in Arizona. The plants are attacked by the disease from the time they have five or six leaves, until their heads are fully matured. Small plants, when attacked, become yellowish in color, stop growing, and fail to head. Such plants produce a few small, yellowish, new leaves, which lie flat on the ground. Headed or partly headed plants, on becoming diseased, usually show dark-brown, dead, irregular blotches and streaks in the leaves. Beginning with the bottom leaves, the affected plants turn brown and wither.

The occurrence of the disease in localized areas is often noticeable and has frequently led to the erroneous conclusion that it is associated with alkali spots. The disease is not always so localized, for diseased plants may be scattered throughout the field. As a rule, infestation becomes more severe as succeeding crops of lettuce are grown on the same land. As far as is known, only lettuce is susceptible. Jagger has developed several strains of New York which are resistant to brown blight. The strain giving the most promise at present has been named "Imperial No. 2." Only brown-blight-resistant strains should be planted on infested soil.

Tip-burn.—Tip-burn is a non-parasitic disease and is most prevalent during the summer, especially when warm, bright days follow a period of foggy or cloudy weather. In a preliminary report, Rawlins and McClain (1925) state that:

. . . the first evidence of the trouble is usually the development of small brown spots near the edge of the upper, more tender exposed leaves. These spots usually develop first at the junction of small veins about ¼ to ½ inch from the edge of the leaf. The development of these small dead spots seems to prevent the passage of water to the edges of the leaf and that portion outside of the spots becomes wilted and yellow and soon dies leaving a dead, brown strip around the edge of the leaf.

Field observations, made by McGinty and Thompson (1925) in Colorado, on the variety New York, indicate the following:

(1) High temperatures encourage but do not cause tip burn; (2) tip-burn may occur when the relative humidity is high and transpiration is below normal; (3) the disease is not due to excessive water loss caused by high transpiration rate.

These authors present data, which show that healthy lettuce plants are higher in monosaccharids, disaccharids, polysaccharids, and percentage dry weight than are tip-burned plants. It is doubtful if the exact combination of conditions causing tip-burn is known. Iceberg is somewhat more resistant to tip-burn than is New York. In California, some promising results have been obtained by seed growers from crossing these two varieties. It has been found possible to combine the resistance factor with the New York type.

Mosaic.—Jagger (1921) has reported mosaic disease as occurring in Florida on the Paris White Cos and Big Boston varieties of lettuce. He was able to transmit it to healthy plants by means of aphis. The spread of this disease can no doubt be retarded by keeping the aphis under control by the use of nicotine sprays or dusts.

Insects

Cutworms.—Probably the most serious insect pest of lettuce is the cutworm, which cuts off the young plant at the ground level. Best protection has been obtained by use of poisoned bait. Dusting or spraying the plants with arsenate of lead is useful when the plants are young but should never be practiced when the crop is approaching maturity.

Wireworms.—Wireworms, at times, cause considerable damage in lettuce fields, especially after alfalfa.

Grasshoppers.—Grasshoppers sometimes devour entire fields of fall-planted lettuce. It is a good practice to burn the grass and weeds and to work the ground along the roads and ditch banks, as the female grasshoppers lay their eggs in the surface soil of these untilled areas. Considerable trouble may be expected from grasshoppers where lettuce fields adjoin alfalfa or pasture lands, if the latter are not thoroughly disked or harrowed in the late fall, winter, or early spring.

When grasshoppers appear in the field, a heavy irrigation is sometimes given to moisten the ground thoroughly. The best method of control, however, is to use the poison-bran mash. This mash should be spread in the early morning, as grasshoppers do most of their feeding during the day.

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CHAPTER XXV

TRAGOPOGON

Salsify is cultivated to only a limited extent in the United States; it is grown mainly as a market-garden crop.

History.—According to Sturtevant, the native home of salsify is in the Mediterranean countries. It has come under cultivation in comparatively recent times; though mentioned by Gerarde in 1597, it was apparently not then used as a food plant. It was cultivated in France in 1612. After this time, the culture became general, and it is mentioned as being cultivated in America in 1806.

Plant Characteristics

Salsify is a hardy biennial. The tap-root is long, fleshy, whitish, and tapers gradually, becoming very slender. The roots appear very much like parsnip, but their diameter is not as large. The edible part is mostly tap-root, only a small portion of the former developing from the hypocotyl. The crown develops from the plumule. The flavor is mild and sweet and reminds one of an oyster, whence the name, "vegetable oyster," or "oyster plant." During the first year, a rosette of leaves develops from the much-compressed stem, or crown. The leaves are alternate, entire, keeled, linear-lanceolate, glaucous, and clasping at the base. During the second year, the stem elongates and branches. The flowers are perfect and are borne in single heads on fleshy, hollow peduncles. They are purple; they open early in the morning and close usually before noon, not to open again. All flowers in a head are open at the same time. The involucre is cylindrical; the linear-lanceolate bracts are nearly equal and in one series. The corollas are ligulate, truncate, and five-toothed at the apex. The anthers are sagittate at the base. There are two stigmatic lobes. The fruit, or achene, is linear, long beaked, and contains a single seed. The pappus is yellowish, plumose, and grown together at the base.

Culture

Salsify is slow growing; it needs a long growing season, to make its maximum development. The best soil is a deep, sandy loam; on heavy soils, too many lateral roots are formed. In the North, where the crop is chiefly grown, the seed is sown in early spring. When the plants have become established they are sometimes thinned to 2 or 3 inches apart in

the row. Cultural directions are about the same as for parsnips. The variety grown most extensively is Mammoth Sandwich Island.

Marketing and Storage

Roots are sometimes dug before they are mature, tops are removed several inches from the crown, and about 12 roots bunched together and tied near the crown and near the root tips. Most of the crop, however, is dug in the fall; a portion is placed in storage, and the remainder, sold immediately upon the market. In mild climates, mature roots are left in the soil over winter. The tops are rather hardy, and the roots are not injured by freezing.

Seed Growing

Most of the salsify seed used in the United States is produced in the San Benito, Santa Cruz, and San Luis Obispo counties of California. The seed is sown in July and August, and the mother roots are transplanted in late fall or early winter. At time of transplanting, roots which show much branching are discarded. Some of the growers space the rows so that the alternating middles are 3 and 4 feet wide. When harvesting the crop, the pickers walk in the 4-foot middles. The production of salsify seed is rather expensive, as it must all be picked by hand; it is best to gather it in the morning, to reduce loss by shattering. If the plants are kept in a growing condition, by giving plenty of water, and the weather is cool and the plants free from disease, seed production continues for a considerable time.

CHAPTER XXVI

CICHORIUM

SECTION A. ENDIVE

Endive is cultivated in the United States to a limited extent only. It is grown chiefly as a market-garden crop near the cities and is used as a salad and, to a lesser extent, as a potherb.

History.—Endive is thought to be of East Indian origin. According to Sturtevant, it was used as a food plant from a very early period, by the Egyptians, and was known to the Greeks. At the time of Pliny, it was eaten as a salad and as a potherb. It was in cultivation in England in 1548, and McMahon mentions it as being cultivated in the United States in 1806.

Plant Characteristics

Endive is a biennial. During the first year, a rosette of leaves arises from the shortened stem, or crown. The leaves are oblong, toothed, or pinnatifid, more or less twisted, and usually somewhat curled on the edges. During the second year, the stem elongates and branches. It is hollow, terete, and smooth or slightly hirsute. The flowers occur in heads. They are perfect, with five-notched, ligulate corollas. They are open in early morning and close usually before noon. The open head is 4 to 5 centimeters in diameter, and the number of flowers per head varies from 18 to 20. The fruit is an achene, with a short, scale-like pappus.

Culture

Field culture and packing of endive are the same as for lettuce, but the plants are somewhat slower growing. The green leaves are more bitter than are the blanched; therefore, the inner leaves are blanched by tying up the outer leaves or by covering when they are to be used as salad. During recent years, some endive has been growing in the West and South for shipment in mixed or straight cars. Only the largest markets, however, are able to handle this vegetable in carlot quantities.

Varieties

There are two types of endive, the curled and the broad-leaved varieties. White Curled, Green Curled, and Moss Curled are examples of the former type, while Broad-leaved Batavian (Escarolle) is an example of the latter type.

Seed Production

The main region for growing endive seed is in the Santa Clara Valley of California. The seed is planted in November or December in rows about 30 inches apart at the rate of 1 to 1½ pounds per acre. In the spring, plants are thinned to about 8 or 10 inches apart in the row. Flower stems develop in May or early June. The crop is cut with a mowing machine, usually late in September. It lies in windrows until sufficiently dry to thresh, which may be 10 days or longer. The threshing is usually done with a machine of the same type as that used for radish. A yield of 600 pounds of seed to the acre is a good average. Smooth-leafed usually yield about 30 per cent higher on the average than curled varieties.

SECTION B. CHICORY

Whitloof chicory is an improved horticultural variety of the wild chicory (*Cichorium intybus*) and differs from the latter in having a much larger tap-root and big, broad, smooth leaves. It is a native of Europe but has become naturalized in many parts of this country. It is grown chiefly as a salad; a small amount, however, is grown for use as a potherb. The seed is planted in the spring; and in the fall, the roots are dug and stored in a cool place, where they will remain dormant. At intervals during the winter, roots are taken from storage and placed in moist soil in a slanting position, and the crowns, covered to a depth of 6 or 8 inches with a sandy soil or pure sand and kept at a forcing temperature of 10 to 20°C. The heads are ready to harvest in 2 to 4 weeks. They are cut off at the base, and a small portion of crown is also removed, to hold the leaves together. The heads are then trimmed and marketed in baskets or hampers.

CHAPTER XXVII

CYNARA

Although the artichoke has been a popular vegetable in southern Europe for over 2,000 years, it has only recently become important in America. Most of the commercial production is at present in California, where 11,000 acres are devoted to the crop, in the coastal region between San Francisco and Los Angeles. The chief producing areas are at Half Moon Bay, near San Francisco, and in the Salinas Valley. As American markets become better acquainted with this vegetable, production will probably increase in other sections.

Taxonomy.—The Globe artichoke has been classified as a distinct species, *Cynara scolymus*, but apparently is only a cultivated form of the wild cardoon (*Cynara cardunculus*). Cynara belongs to the *Liguliflorae* group of the *Compositae*. Another plant sometimes used as a vegetable, the Jerusalem artichoke, also belongs to the *Compositae* but is in the *Tubuliflorae* group, having both disc and ray flowers. Hence, the two plants popularly called "artichokes" are distantly related. Globe artichoke resembles the common thistle; Jerusalem artichoke is a tuber-bearing sunflower. The name "artichoke" is of Arabic origin, meaning "barbs of the earth," and was probably applied to Globe artichokes over a thousand years before Jerusalem artichokes were found in the New World.

History.—The artichoke is a native of North Africa, where plants are still found growing wild as desert perennials. It was cultivated at a very early date in Mediterranean countries. Thus, we find Pliny, in the first century A.D., speculating about the possibility of introducing improved varieties from Algeria to Italy. According to Sturtevant, artichokes were not introduced to England until 1548. Their introduction and popularization in the United States is due largely to the French people of Louisiana and the Italians of California.

The cultivated form of artichoke was probably developed by selection from the wild form. Both wild and cultivated plants are very heterozygous, presumably because of the prevalence of cross-pollination. Diverse types, mostly inferior to the cultivated varieties, arise through seed propagation. Trabut (1910) records the appearance of a spineless individual, apparently as a mutation, among a large number of the ordinary spiny wild plants in Algeria.

Plant Characteristics

The artichoke is a herbaceous perennial, the plants being renewed from year to year by lateral offshoots just below the surface of the ground. While the crowns of the individual plants decay after 1 year's growth, renewal by offshoots from the rootstock makes the crop a perennial from the cultural point of view. Each lateral offshoot forms a rosette of leaves, in the center of which the flower stalk appears somewhat later.

The rosette leaves are large, deeply lobed or pinnately divided, and covered with grayish, woolly pubescence. The long, fleshy petioles are edible and are sometimes blanched by mounding the plants with soil. The cauline leaves are smaller.

The large, globular flower heads are borne terminally on the main axis and on the lateral branches. They are covered with an involucre of several rows of imbricated bracts. The bracts are thick and fleshy on their basal portion and constitute the chief edible part of the plant. The receptacle is a broad, thick, fleshy plate and is also edible, as are the flower primordia borne on it, in the early stages of their development. The florets have a slender corolla tube and are set closely together upon the receptacle. When in full bloom the flower heads resemble a gigantic purple thistle. The conspicuous, elongated portion of the florets is the pistil, which appears to be receptive throughout its upper portion. The pollen is discharged from the authus on the side of this stigmatic prolongation of the pistil. The flower stalk grows to a height of 4 or 5 feet, branches, and bears a number of "buds," really unopened heads. The flower stalks wither when the seeds mature. The seeds are thick, compressed achenes, with a tough, hairy pappus. The bracts become hard and sharp and, near the tip, have a rudimentary spine, which, in wild artichokes and in the cardoon, is well developed.

The composition of the whole bud, as determined by Okay and Williams (1920), is as follows:

	Per Cent		Per Cent
Moisture	85.5	Protein	2.8
Ash	1.1	Ether extract	1.4
Crude fiber	2.4	Total carbohydrate	6.8

The carbohydrate consists almost entirely of inulin, which, on hydrolysis, produces levulose sugar. Hence, the value of artichokes in the diet of diabetics. Morgan and Stephanson (1923) found that, when freshly boiled, artichoke is a rich source of the fat-soluble vitamine *A* and of considerable value for the water-soluble vitamine B.

Climatic Requirements

While the vegetative parts of the artichoke plant are resistant to temperatures several degrees below freezing and the rootstocks survive

even lower temperatures, the commercial production is confined to localities having mild winters. Wellington (1917) reports that the plants can be overwintered successfully in central New York by mounding the rootstocks with coal ashes. In sections having cold winters, the buds are formed during late June and July. The high temperatures prevailing at that time prevent the development of large, well-formed buds. In southern localities, where bud development can be brought on during fall, winter, or early spring, buds are of better quality. The California coastal region is well suited to the production of high-quality artichokes, because of its cool, humid climate. Also, its mild winters, which permit the production of a large part of the crop during the winter months when prices are high, make the crop a profitable one.

During cool weather, the bracts become especially thick and fleshy and enclose the flower head tightly, and floral development is slow; these conditions produce large artichokes and the highest edible quality. With high temperatures, full sunshine, and long days, the floral organs develop rapidly, the bracts spread outward, and soon the flower heads pass out of the edible stage.

The artichoke plant often escapes from cultivation and grows wild on poor, dry soils. For production of large, tender buds of good quality, however, abundant moisture and heavy manuring are required. It is an interesting contrast that the artichoke plant, a native of hot, dry deserts, under cultivation produces best in moist, fertile soils and cool, humid climate. Some of the differences between the wild and cultivated forms are no doubt due simply to variations in soil and climatic conditions.

Cultural Considerations

Propagation.—Since the artichoke does not come true from seeds, it is generally propagated vegetatively, by removal of the suckers or offshoots from the tap-root. Furthermore, production of buds commences a year sooner from suckers than it does from seedlings. Wellington (1917) observed great variation in production on different individual plants grown from vegetatively propagated plants; some variability in plant type is noticeable, also, in commercial fields. It is advisable to select propagating material from plants of the most desirable type.

The suckers form during late summer, after the flower stalk dies. They may be separated from the parent rootstock with a spade and transplanted during the fall or winter. These plants will produce a single flower stalk with several buds the following spring, and in the second year, there will be a cluster of several plants, each with its flower stalk. After 7 or 8 years, plants in each clump become so numerous,

that the crowding results in inferior development, and the plantation should be started anew.

Field Planting.—Each sucker at time of planting should have a small piece of the parent rootstock, and the new fibrous roots should have started on the basal portion. The top is cut off about 6 inches above the soil line. In mild climates, fall or early winter planting give better results than later planting. Planting distances are about 4 by 6 feet apart.

In the commercial plantations in the coastal district of California, a small crop of buds is harvested from the plants during the spring following transplanting. In April or May, when picking is no longer profitable, harvesting ceases, and the plants are allowed to dry. Or, at the end of the picking season, the stems and leaves may be cut, chopped, and ensiled for feeding dairy cattle. About 3 or 4 tons of silage, equal in feeding value to that of corn, are produced from each acre. If the plants are not to be ensiled, they are cut off just below the surface of the soil and burned. After lying dormant for 6 to 8 weeks, growth is started by irrigation. The new plants develop during the summer, and bud production commences in September. Development is slow during the colder months, and the pickings are light until February, when the production increases rapidly to a peak in March. The abundant supply, together with competition from other fresh vegetables, depresses the price so that it is no longer profitable to market the crop. Profits depend largely on the proportion of buds maturing in fall and winter.

Under eastern conditions, propagation is done in spring; the tops are cut and burned in the autumn, and the roots are protected during the winter.

Harvesting and Marketing

The stem is cut a short distance below the bud, when the latter have attained maximum size but before the bracts begin to open.

For shipment, California artichokes are packed in large lugs, or chests, containing 20 dozen buds. Smaller packages, containing 3 to 5 dozen buds, are becoming more popular. The larger sizes of buds are most in demand, but the small buds are edible, and these should be used when artichokes are grown in unfavorable localities for home use.

Varieties

Only two varieties are used in America, Large Green Globe being most important. The Purple Globe variety has smaller buds the outer bracts of which are suffused with purple pigment. Vilmorin (1883) lists 13 varieties; apparently, there are several types in use in southern Europe, but, in general, the varieties are not very distinct.

Diseases and Insects

The artichoke plant as grown in the United States is remarkably free of insects and disease pests. The following sometimes cause injury.

Botrytis Rot (*Botrytis* sp.).—This disease occurs in artichokes chiefly during shipment and after arrival at the market. It is said to be almost the only cause of loss in transit, according to Link, *et al.* (1924), who found losses of from 2 to 100 per cent in carlot shipments arriving on the eastern markets. Much loss previously attributed to freezing injury is due to *Botrytis*. The buds are affected with a brownish decay at the base and on the tips of the outer bracts, which often extends into the heart of the bud, with a more or less abundant growth of grey mold. Link, *et al.* concluded that spore contamination in the field at cutting time is probably the chief source of the disease, the fungus gaining entrance through the wound made in cutting or through the split ends of the bracts. The fungus is able to grow at very low temperatures, hence, is not checked completely by ordinary refrigeration. In and around the field, dead-plant materials on which the fungus grows and sporulates should be burned or otherwise disposed of. The artichokes should be picked and handled only when dry, as moisture favors inoculation and growth of the fungus.

Artichoke Aphis (*Myzus braggi*).—This green Aphis occurs in the South and East. It generally attacks the undersides of the leaves and produces an abundant excrement, or honey dew, in which molds grow, blackening the foliage. This honey dew attracts flies and other insects. According to Jones (1918), this and other aphis attacking artichokes, and especially the bean aphis, are controlled by a nicotine spray (Blackleaf-40, 1: 1,000 parts of water) to which has been added 1 pound of laundry soap to each 25 gallons of solution. Yellow thistle is a host plant for the artichoke aphis and should therefore be destroyed.

Plume Moth (*Platyptilia carduidactylia*).—Considerable losses occur in California from the larvae of these insects boring into the growing buds and making them unmarketable. Thistles afford an alternate host and should be kept down in the vicinity of artichoke fields. According to Essig (1922), arsenical sprays and dusts and also nicotine dusts are effective in controlling this insect, if thorough applications are made immediately after each picking. Another important control measure is to destroy completely the tops of the plants, immediately after the end of the picking season.

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